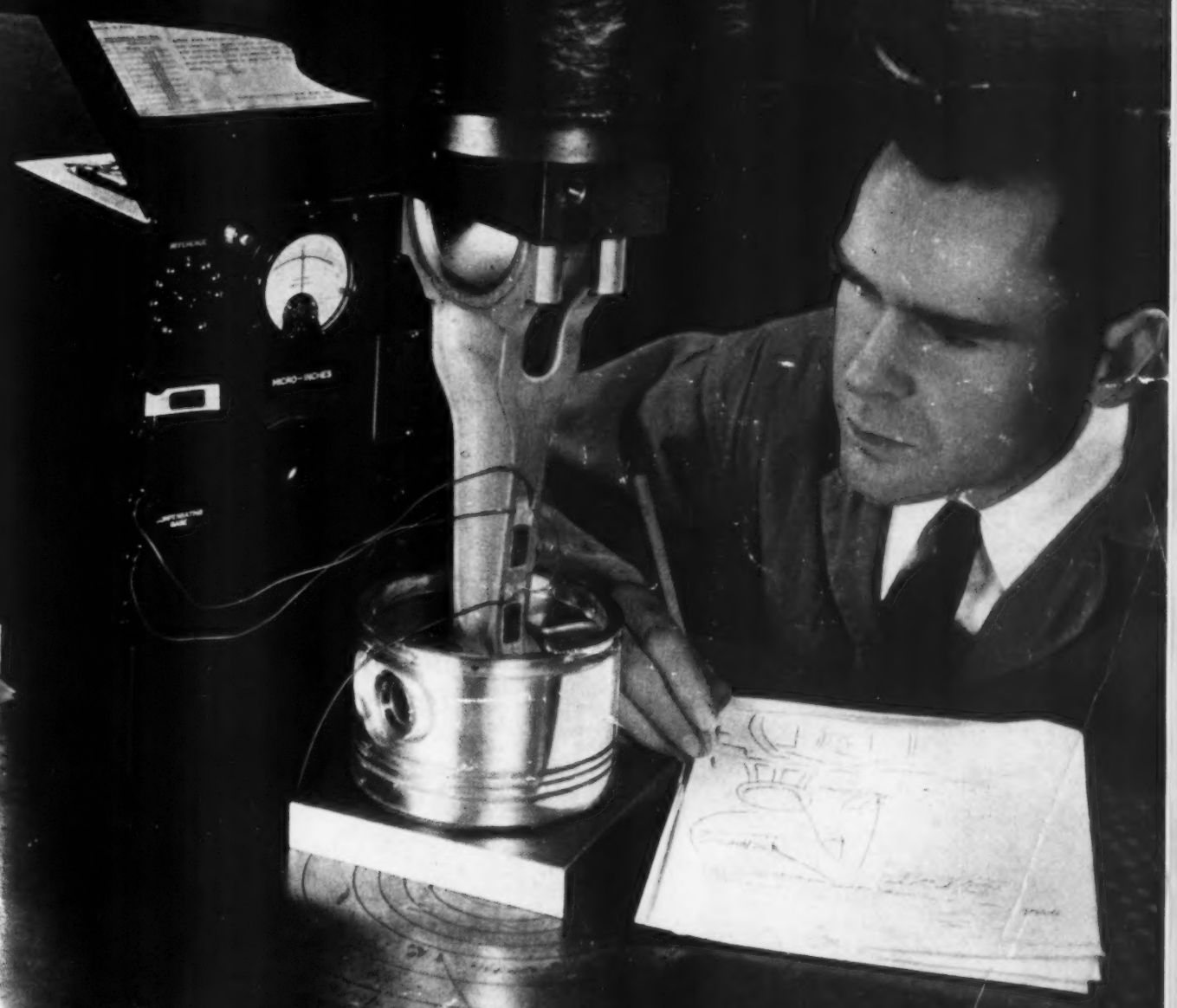
PRODUCT ENGINEERING

APRIL 1948



MEASURING STRAIN

IN THIS ISSUE — How to Organize for Experimental Stress Analysis + Precision Investment Casting + Office Design + Brazing Techniques + Low Scrap Design

A McGraw-Hill Publication

Crown Cork and Seal Company, Baltimore, Md., uses austenitic chromium-nickel stainless steel to assure the sanitation, durability and trouble-free performance of their CEMAC 28 unit. Easily cleaned, this stainless steel is highly resistant to foodstuffs, atmosphere, most organic and a great many inorganic chemicals, and to dyes and sterilizing solutions.

Use of STAINLESS STEEL.... *minimizes "CLEAN-up" time*

and CUTS MAINTENANCE COSTS, *too!*

You can save money—and time too—because of the ease with which this equipment can be cleaned.

The rotary vacuum filler-capper, shown above, is equipment of this kind. It saves money, time and labor, *day-after-day.*

Easy to clean and keep clean, it also combats wear and general abuse because it's made of chromium-nickel austenitic stainless steel.

Corrosion-resistance combined with high strength make chromium-nickel stainless steel an ideal material for equipment. Considerably stronger than plain carbon steel, it permits cutting bulk and deadweight without sacrificing strength or durability. In addition it may be readily formed, and is easy to weld.

Leading steel companies produce stainless steel containing nickel in tubular, sheet and strip form. A list of the sources of supply will be furnished on request.

EMBLEM OF INCO SERVICE
TRADE MARK

Over the years, International Nickel has accumulated a fund of useful information on the properties, treatment, fabrication and performance of engineering alloy steels, stainless steels, cast irons, brasses and bronzes and other alloys containing nickel. This information is yours for the asking. Write for "List A" of available publications.

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N.Y.

VOLUME 19

PRODUCT ENGINEERING

NUMBER 4

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FRONT COVER—Taking strain gage readings on a diesel engine connecting rod at General Motors Research Laboratories. Stress concentration areas first have been detected by brittle coating analysis. Kodachrome courtesy of General Motors Corporation.

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IN THIS ISSUE

Experimental Stress Analysis

Since the appearance, in December 1946, of a 16-page symposium on Experimental Stress Analysis, PRODUCT ENGINEERING has been deluged with requests for more information. Letters from all over the world reveal the growing appreciation of this design technique, which is proving more valuable every day. In answer to these requests, PRODUCT ENGINEERING follows up the symposium of case histories with a detailed discussion on how to set up an experimental stress program in your plant. Starting on page 113, these vital questions are answered: When should experimental stress analysis be considered? What are the relative merits of photoelasticity, brittle coatings, electric strain gages, and mechanical extensometers? What equipment is required? What does it cost? Where can one learn more about these methods for creating better designs?

Precision Investment Casting

Precision investment casting became a reliable engineering process through the need for accurately formed parts, difficult or costly to machine. Although its general availability to industry was announced just after the war, its engineering properties are only now being evaluated. Beginning on page 81, Edwin Laird Cady discusses design requirements for precision castings and the characteristics of the materials used.

Spring Redesign

Time and effort are often expended in redesigning springs for circuit breakers and other calibrated instruments—the problem being to reduce spring stress without changing the spring rate, installed height and solid height. On page 143, A. Bodenschatz presents formulas for redesigning springs of fixed length and spring rate.

Delayed Magnetic Latches

Engineers who may be familiar with magnetic opening and closing devices will be particularly interested in magnetically-latched relays which have a "memory" among other things, they always "remember" the last position of the armature. Beginning on page 110, Fritz Didszuns discusses several different types of memory relays that use magnetic latching.

Sprayed Wiring

The trend toward mechanization in design—use of prebuilt and standard components—continues to grow. Electric wiring is being affected by three types of "prefabrication": Printed electric circuits, first reported on page 134 of July 1946, PRODUCT ENGINEERING and evaluated on page 158 of this issue; stamped wiring, see page 168, September 1947, PRODUCT ENGINEERING; and sprayed wiring. On page 141, John T. Collier describes the technique, advantages, limitations and cost of sprayed metal circuits for mass production of electric components.

Design Advantages of Brazing

Use of new production techniques, to utilize design advantages of assembled construction, became highly developed during the war. Copper furnace brazing, for instance, first discussed in PRODUCT ENGINEERING, October 1946, has found a permanent place in engineering design because of cost reduction and production shortcuts. Design advantages of this, and five other brazing methods are discussed by S. De Domenico and A. Squire, Westinghouse Electric Corporation, on page 86. Messrs. De Domenico and Squire also describe physical properties of brazed joints and influence of materials.

Analyzing Machine Noise

An ever present aspect of the design engineer's art is the understanding of machine noise and how to reduce it. Based on a series of studies performed at the Armour Research Foundation of the Illinois Institute of Technology, Dr. Howard C. Hardy concludes a discussion of noise fundamentals. Beginning on page 137, Dr. Hardy outlines a systematic procedure for reducing the noise level in machinery.

Hydraulic Shock Absorber Orifices

Modern machines and equipment require mechanisms specifically designed for control of shock and vibration. Many such devices are hydraulic, and require the use of some type of metering orifice, through which liquid passes. On page 146, Joseph Brown of the Naval Aircraft Factory follows his first article, February issue, with a practical discussion showing how the equations he derived can be used to design several types of orifices.

Designing for Low Scrap

Cost-conscious designers are constantly on the lookout for economical methods of fabrication. Often a worthwhile saving can be effected in the initial step—laying out of the sheet stock preliminary to fabrication. On page 150, E. F. McCaleb, General Electric Company reminds designers that proper "nesting" may allow increased numbers of finished parts to be produced from the same piece of initial stock. Sometimes the shape of a part can be changed without impairing its load carrying ability.

MAY HIGHLIGHTS

ELECTRICAL WIRING FOR MOTOR DRIVEN MACHINES. Special editorial insert, 16 pages, dealing with power and control wiring details, types of insulated conductors, design factors and installation requirements for obtaining efficient machine performance, trouble free operation and attractive appearance.

CELLULOSIC PLASTICS AS ENGINEERING MATERIALS, by Marie Bentivoglio and Millard Demarest, Plastics Division, Celanese Corporation of America. Properties and applications of this basic group of plastics, which were previously considered by some as materials suitable only for decorative and novelty products. The authors prove the industrial utility of these materials.

PHOTOELASTIC INVESTIGATION OF STRESS-RELIEVING FILLET CURVES, by Everett Chapman. Few engineers appreciate the rapidity and simplicity with which many design problems can be resolved photoelastically. Concentrations of local stresses where machine components meet can be studied quickly through photoelasticity, as is shown by this study of keyway fillet blending curves.

Promoting the Profession Among Students

IN RECENT YEARS great emphasis has been placed on ways and means to achieve a higher standing and appreciation for engineers. In establishing the Machine Design Division of the American Society of Mechanical Engineers, one of the objectives was the elevation of the standing of the design branch of mechanical engineering.

The standing of any profession or group is determined solely by the stature and abilities of the members thereof. Recognition is achieved only by noteworthy accomplishments, which in turn depend on the average of the abilities of the individuals that comprise the group. Unless outstanding men are attracted to a profession, that profession cannot grow in stature.

Thus it is that the rise or fall of a political, social or professional body is determined not by to-day's leaders but by the guidance given to the youths who in their later years assume leadership. Full of vigor, enthusiasm and ambition, pliable youth readily gains impressions and develops convictions that later become the bases of far reaching decisions. Destinies are born when the seeds of conviction take root.

Obviously, if the professional standing and recognition of the engineering design profession is to be increased greatly, two things must be done. The best qualified graduating engineers must be attracted to the profession and the student engineers must be given a true picture of the work and career of a design engineer. Impressions must be planted. Convictions must be born. It is the responsibility of the profession to see that both are done.

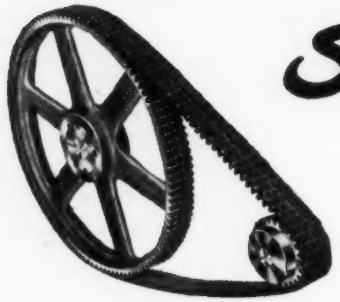
Under the auspices of the Machine Design Division of the A.S.M.E., a plan to accomplish these objectives has been put into effect. The entire credit for this undertaking goes to B. P. Graves, director of engineering of Brown & Sharpe Manufacturing Company, who proposed the project and was appointed chairman of the committee to put it into effect. Ben Graves and his committee will select speakers from among outstanding design engineers to address engineering students on the work and career of a design engineer. Engineering schools will be advised of the availability of these speakers to address student A.S.M.E. meetings and class room groups. It is hoped that by this means the false notion prevalent among students that designing is a drawing-board pencil-pushing job, will be broken down and outstanding students will be attracted to a design career.

Many were aware of the desirability and need for a program to stimulate the interests of students in engineering design. But it was Mr. Graves who thought the problem through, planned the solution and proposed it. Naturally, he was appointed chairman of the committee to put the plan into effect.

We urge every engineer to support this program in every way possible. Also, the schools and colleges should take advantage of this great opportunity to bring students closer to the realities of the problems and activities of design engineers in industry.

G. F. Nordenholt

MORSE ANNOUNCES NEW SILENT CHAIN STOCK DRIVES!



Users benefit by Morse standardization; early delivery available

INDUSTRY will profit in many ways by the development of this new silent chain standardization program.

A reduction in the number of parts carried in stock cuts down inventories, reduces storage space and simplifies ordering.

With industrial distributors stocking these new Morse *packaged* silent chain drives, industry will be able to obtain complete silent chain drives off the shelf, ready for immediate installation.

This new standardization program is certain to result in a sharp increase in the use of silent chain drives in industry.

Two large Morse plants, in Detroit and Ithaca, are meeting all schedules to make these new standardized silent chains and sprockets available.

Major industrial distributors everywhere will handle the new standardized Morse Silent Chains and Sprockets as they now do other Morse products.

Morse plans extensive stock drive program; Taperlock bushings standard

TOOLING has been completed at Morse for ½" and ¾" pitch chain sizes made to the new Silent Chain Standards. Also announced is a silent chain stock drive program covering both sprockets and chains.

The company's new stock drive program will include a series entirely different from the present line. All popular widths of chains will carry a single center guide link.

Sales Manager outlines plans

The General Sales Manager of Morse says that, henceforth, Morse cast-iron stock sizes of driven sprockets will have finished bores prepared for use with Taperlock bushings. Bushings will be available with finished bore diameters in increments of $\frac{1}{16}$ inch.

It is also pointed out that Morse driving sprockets will be furnished with finished bore diameters in the N.E.M.A. standard shaft sizes, complete with keyway.

Morse Chain's six dual-duty sprocket face widths will operate with eleven stock chain widths. It is possible to obtain as many as 40 ratios for each stock chain width. Such combinations are expected to cover 95% of the ratios required by all users.

Standardized stock silent chain will continue to be furnished with the exclusive feature — the Morse Rocker Joint.

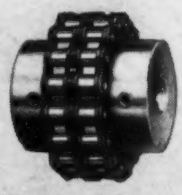
Write Morse Chain Company, Department 139, Detroit, Michigan, for Catalog C-71-48 giving complete information on the new Morse Silent Chain and Sprocket standardization program.

MORSE

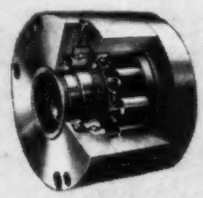
MECHANICAL POWER TRANSMISSION PRODUCTS

A PRODUCT OF BW BORG-WARNER

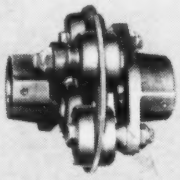
Morse Roller Chain Drives for positive power transmission.



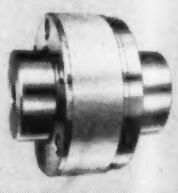
Morse Chain Couplings, for economical, easy installations.



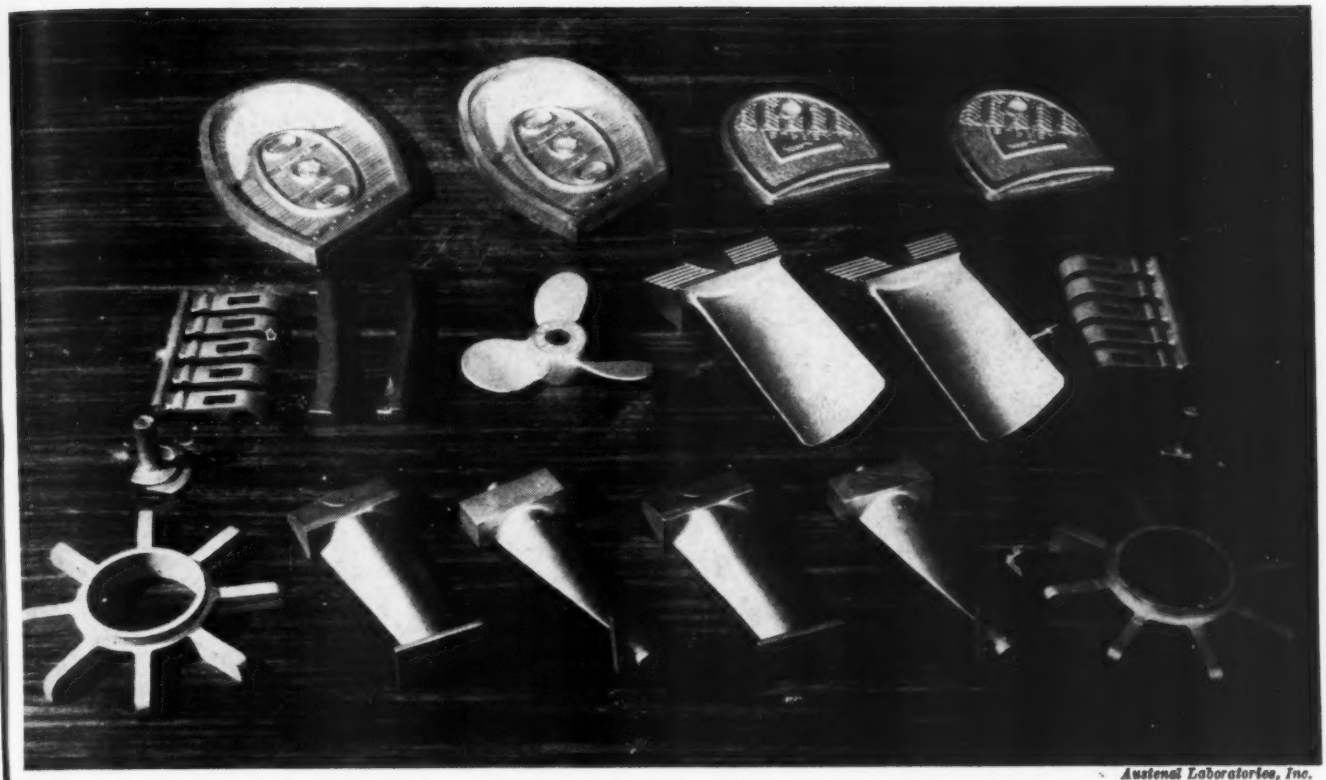
Morse Free Wheeling Clutch for positive indexing.



Morflex Couplings are torsionally flexible and compensate for misalignment.



Morflex Radial Couplings are especially suited for heavy torque loads.



Austenal Laboratories, Inc.

Precision investment cast parts. Top row 18-8 stainless steeel molds. Middle row, 8620 steel gripper fingers, I-40 Vitallium turbine blades, high-carbon high-chrome stapling machine parts. Bottom row, 316 stainless steel webs, 6059 alloy gas turbine blades.

Precision Investment Casting

Characteristics of alloys used. Effect of machinability on design of precision investment castings. Detailed design procedure for high and low machinability alloys.

EDWIN LAIRD CADY*

THE FIRST POINT TO REMEMBER about precision investment casting is that, although made to precision tolerances and metallurgical specifications, they still are castings. They are made by pouring metal in the liquidus state (sometimes, but rarely, in the mushy range), letting that metal cool down through its mushy, solidus, plastic and solid-critical ranges, and either permitting or forcing it to cool to room temperature.

While going through the complexities of these temperature ranges, alloys behave in various ways. In fact, any single alloy if cast to different shapes may behave in different ways. From this, two simple rules can be set up:

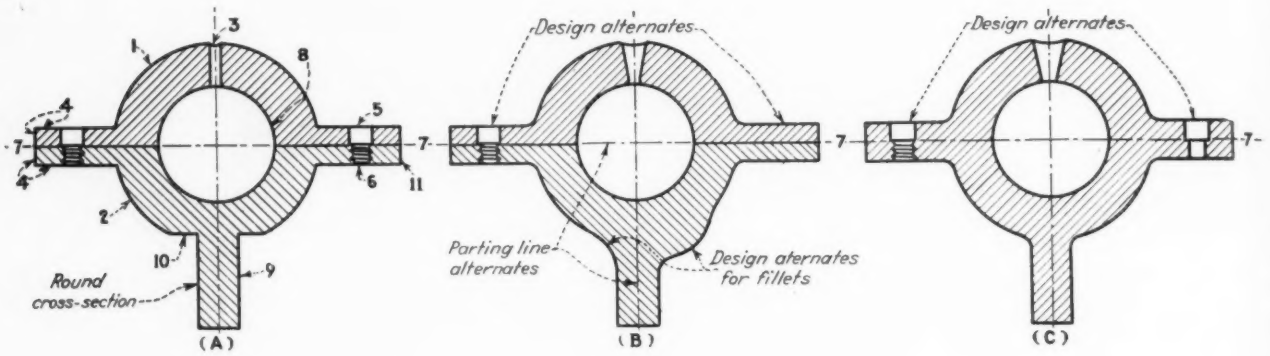
1. When precise contours and close tolerances are important, work out the widest list of alloys suitable for the product and let the casting contractor or the casting department (the caster) make the choice.
2. When the range of alloys which will fit the end uses of the product is narrow, work very closely with the caster to get a casting design which is most economical to cast in those alloys.

Between the extremes of (1), a product which can be cast in almost any alloy, and (2), one which can be made of only one alloy, there are many options. Failure to consider these options is perhaps the greatest obstacle to economy in precision investment casting design. That failure is largely psychological.

A great majority of metal products are fabricated from wrought stock. Depending upon the sizes and shapes he wants and the quantities in which he buys, the fabricator of wrought stock is or is not able to get the alloys he wants. Usually he takes the alloys he can get and makes them do. Failing that, he takes the sizes and shapes he can get in the alloys he wants and changes his product designs or production procedures accordingly. He is not accustomed to thinking in terms of wide options as to alloys in the sizes and shapes he would like to have for his product. He specifies for precision investment casting the same narrow range of alloys that he would consider if he were buying wrought raw materials to fabricate. But if he is to get the best from this process he must change his design habits in selecting alloys.

To attempt a listing of alloys and what designs may be investment cast from them is impractical. The options for casting production procedures are too wide. Too many meeting grounds exist between product requirements and production economics. There are no "alloys typical of this process" nor "casting contractors typical of this field" in the sense

* *Mr. Cady is serving on one of the design subcommittees of the American Foundrymen's Association.*



Element	Manufacturing Operations Affecting Design		
	Machined (A) from Solid	Cast (B) in Machinable Alloy	Cast (C) in Low Machinable Alloy
1 Cap 2 Bearing	Separate pieces	Separate pieces	Single casting— Friction saw along 7-7
3 Oil hole	Drill	Cast taper and flare	Cast taper
4 Lug surfaces	Finish one surface for control surface for boring 8	Same as (A)	Leave as cast
5 and 6 Cap screw holes	Drill 5 for cap screw, 6 for tap; tap 6	Cast 5 and 6, chase thread or do not cast holes and drill and tap as in (A)	Cast hole and thread, with thread below 7-7 or cast single hole with two dia, one for cap screw shank, one for thread root; tap.
7 Mating surfaces	Finish	Finish	Finish after friction cutting
8 Bore	Machine 1 and 2 independently; assemble using 9 as control surface; bore	Cast 8 with slight amount of straight wall at mating surfaces to allow for machining of mating surfaces. Bore if necessary	Same as (B) casting
9 Shank	Turn 9 in lathe.	If parallel faces are required, cast with vertical parting line or if taper of .001 in./in. is allowable, horizontal parting line may be used.	Same as (B) casting
10 Shank juncture	Shoulder as generated by cutter	Cast with generous radius if machinability is fair. If machinability is good, cast with rib and machine away	Cast with minimum permissible fillet and grind
11 Exterior corners	Sharp or else broken by special operation	Cast sharp or broken	Cast mildly broken

that these might be listed for the die castings business. The question of what can be done and the answering query of how much it is worth to do it can lead the discussors to too many different conclusions. Precision investment casting has added enormously to the procedural options which exist within the casting field. And the options in the foundry business always have been high in number.

There is, then, no industry in which thorough discussions between designer and producer are more important. Nevertheless, a few guide posts to the fitting of alloys to product designs, or the reverse, can be set up.

Pouring Temperatures. Low pouring temperature alloys generally can be cast to the highest accuracies, intricacies, surface finishes and with the least need to make design changes to simplify casting.

The dividing line between high and low pouring temperatures is about 2,150 deg F. So far as pouring temperatures alone affect them, casting problems increase as pouring temperatures get above this figure.

Low pouring temperature metals like bronzes, silver alloys and some of the aluminum alloys were the first to be precision investment cast on an industrial basis. The results achieved with them were remarkable. These results were dramatized in technical literature, and product designers were given a false first impression of the precision casting process. That impression constantly bothers the high pouring temperature ferrous alloy casters.

Some of the low pouring temperature alloys can be cast readily to limits of ±0.002 in./in. For some of the highest pouring temperature alloys,

limits of ±0.005 in./in. can be held in production. Lower limits than these are possible but increase production costs.

THERMAL CONDUCTIVITY. If the thermal conductivity of an alloy is too high there are casting difficulties because progressive disposition of cast metal is not easily obtained. Heat flowing from the molten portion of the metal tends to keep all areas of the casting within the mushy, if not within the molten range, until the total loss of heat is sufficient to permit the entire casting to cool. There are casting techniques, largely those of controlling the temperature of the investment, for dealing with this problem.

Nevertheless, extremely high conductance alloys of aluminum or magnesium cannot be cast to high intricacies and accuracies as easily as some of the low melting point alloys which have somewhat lower conductances favoring progressive disposition.

Very low conductance, if accompanied by high specific heat, makes a "sluggish" alloy. The surface tends to solidify easily. Progressive disposition from the surface inward takes place. Deep in the interiors of thick sections the solidification may be incomplete while the exterior has fully solidified. At best the granular structure will differ between the first and last areas to solidify, the last areas generally having larger grains. The worst is that the last areas to cool may have an insufficient supply of molten metal and porous or even dendritic areas may form. Because of this, parts cast in sluggish alloys must be designed to speed heat flow from thick sections as quickly as possible. Ribs and fillets properly located, are usually used. These are not so important for high-conductive alloys.

Within the sectional thicknesses cast by this process, (0.50 in. is the common limit and 5.0 in. probably is the maximum excepting in highly unusual cases) high conductance alloys are far more independent of section thicknesses. The high conductance alloys are castable in any thickness from less than 0.010 in. to 5.0 inches. The sluggish alloys are usually not cast to less than 0.040 in. or more than 0.375 inch.

High conductance alloys, especially if highly liquid and free flowing when molten, are somewhat independent of gate positions on the castings. With pressure methods common to precision investment casting, or even with reasonably good static casting methods, gates will fill out all sections and continue feeding until solidification is complete. But sluggish alloys may need gates generous in size and no more than 1.250 in. from any area of the casting. The gate area must be removed by hand or even a precision grinding operation, with consequent problems of costs and accuracies and surface appearances. Consequently gates must be chosen carefully to satisfy both casting and machining requirements.

Some of the stainless steels and most of the high alloy steels are sluggish. The problems of sluggishness are common to heat treating and therefore, the sluggish alloys are known to every heat treating department.

Beryllium copper is an alloy low in pouring temperature just about right in thermal conductivity, and heat treatable to 175,000 psi. It also has high fatigue and wear resistance and is used widely as an alloy for precision investment casting. Brasses, bronzes, nearly all of the carbon steels, and the stainless steels lie within the medium conductivity range.

THERMAL EXPANSION. Alloys high in thermal expansion not only tend to crush cores as they shrink, but also shrink away from the original contours of the investment cavities. The force needed for crushing the investment material can distort the plastic metal. The extra space between the investment and the casting when the metal shrinks, gives room for warping if there is a tendency to warp.

It is practical to strengthen the investment material, or some parts of it such as cores, and resort to shrink restraint to control warpage, provided the metal is not hot short. But shrink restraint can add to cost.

Thermal expansion is likely to be high for high conductance metals. When it is, these metals do not need fillets and ribs for heat conductors. But, if the design calls for close control of warp, fillets and ribs can be used to advantage.

HOT PLASTIC RANGE. As they cool, alloys go through varying ranges of plasticity, stiffness generally increasing with coolness. The thin sections cool first, and by accumulating strength deform or "shrink" the thick ones. But the thick sections later pick up cold strength and may in turn pull the thin ones out of shape, tear them or set up residual stresses. All of this is known to engineers familiar with casting, heat treating or welding processes.

If the hot plastic range is long, or if the alloys are quite plastic when cold, then, if thin sections are joined to thick ones, the deformation may be severe but the residual stresses mild. But if the hot plastic range is short, the metal accumulates strength rapidly or even abruptly as it cools and, although the deformation may be less, the residual stresses are severe. Fortunately, in precision casting, deformation and residual stresses can be controlled by controlling flask temperatures. Flasks can be cooled so slowly that undesirable warpages and strains do not occur. This sometimes results in poor grain structure within the castings. And it adds to production costs.

Many casters prefer to break castings out of the flasks first and then make a separate operation of stress relieving if any is needed. This has advantages but cannot reduce warpage.

Fillets, ribs, shrouds and other heat distributing features can reduce warpage and residual stresses. It sometimes is practical to add "false" areas which will take the stresses and be deformed or fractured by them, these areas to be machined away from the castings. Gates sometimes can be designed to be false areas or even to act as ribs, provided there is no design feature which forbids their being positioned for this.

Holes which have no useful or adverse effects upon product designs sometimes can be added to give the shrink forces something to do other than pulling the casting out of shape. They are especially useful when the surface alloy tends to solidify first and create shrink forces in the interior metal. Used for this purpose, the holes are deformed and porosity is reduced. Holes also can be designed to weaken the areas of castings where deformation will do no damage and so prevent deformation of more critical areas.

MUSHY RANGE. A wide mushy range of an alloy may result in segregations of some of the metal constituents within the castings, especially if some of the metals or some combinations of them have materially different solidification temperatures than others. Also, segregation may be promoted by differences of specific gravities of elements, especially if centrifugal casting methods are used. This produces a non-uniform casting.

Segregation may take place at the entire skin or outer surface area, producing either a desirable or undesirable surface. The segregation may concentrate the most desirable elements in the casting itself and deplete the sprue and runners of them thus

getting a casting which is better than the alloy melted. Or the opposite effect may occur, although this is largely within the control of the caster.

As with nearly everything else regarding precision investment casting, the goodness or evil of segregation depends upon the alloy, the end purpose of the casting, the design, and the skill of the caster.

HOT SPOTS. A hot spot is an area from which heat cannot escape readily and to which, or through which, heat flows continuously while passing from one area of a casting to another. In short, a hot spot is an area which cannot cool and is not permitted to cool as rapidly as it should. Re-entrant angles, interior angles and under-cuts are hot spots. A hot spot remains molten or mushy after the metal about it has solidified, and remains plastic after that metal has stiffened. Therefore, a hot spot area is likely to deform, have residual stresses or have poor metallurgical properties compared to the rest of the casting.

Many of the hot spots found in designs offered to the casters for production serve no useful design purposes but are hangovers from designs intended to be machined. They may often be avoided by specifying generous radii in place of the smaller radii carried over from machine design practice. Larger radii are better conductors of heat and also strengthen the casting.

Hot spots do the most harm in high pouring temperature alloys, having low heat conductivity and strong segregation tendencies. The length of the hot plastic range may or may not make a difference. But if hot spots must be tolerated, the casting alloy should be carefully selected.

MACHINABILITY. One of the purposes of precision investment casting is to generate precision contours which are more costly or difficult to produce by other methods. It is rule number one of most casters never to generate by casting any contour or dimension which could, with equal or lower cost, be generated by machining. A wise balance between casting, machining and other operations is the essence of precision investment casting economy.

It often is cheaper to drill holes than to cast them. The exception is a hole which is merely a passage for liquids, gases or solid objects and needs no real accuracy of either dimensions or contours. Threads usually can be cut more economically than they can be cast, and so can gear teeth.

The machinability of the alloy makes a difference. Some of the alloys easiest to cast are easy to machine; striking a balance between operations requires careful design.

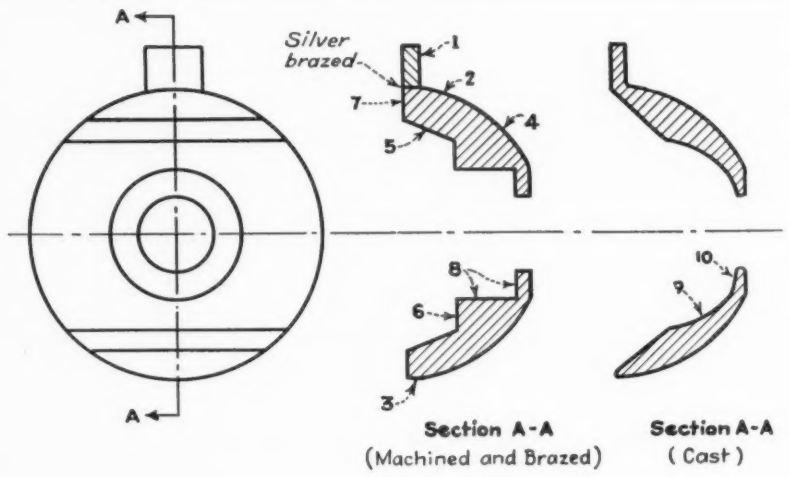
Shown in Table I are several designs for a plain split bearing. These sketches illustrate the importance of careful design when the part is to be precision cast.

When alloys are easy to machine, full advantage may be taken of ribs, fillets, shrouds and other features which solve heat transfer and casting warpage problems, the intention being to machine these sections away after the casting is finished. Unnecessary as these features may appear to be in given cases, they do result in lower spoilage and rejection of castings. The rejection rate, governing the number of flasks which must be prepared and poured, is a major determinant of castings costs.

Some of the alloys regularly precision investment cast are almost impossible to machine, and can be ground only with diamond wheels. Some of the high cobalt alloys are examples. The emphasis then is placed on spending more money on casting techniques to avoid machining. But there are many designs on which shrouds, ribs, brackets and fillets are easy to cut off with the diamond wheel, and for which they solve severe production problems.

Threads may be cast in alloys of low machinabilities, then either chased or ground for final accuracy, but are not as good as outright cut threads on alloys of higher machinabilities.

There is no precision investment cast alloy on which no secondary operations whatever can be performed. It always is feasible to strike balances between casting and secondary operations. For any one design, the choice between machining and casting can only be made after the designer has had a chance to weigh all the pros and cons. Sometimes the nature of the part and its function allow an easy decision. Figs. 1 and 2 show



1. As machined from bar stock.

(a) 1 and 2 are separate pieces, silver brazed.

(b) Edge 3 is unmachined to provide a convenient surface for brazing.

(c) 4 has a spherical radius requiring careful machining.

(d) 5 is a milled channel. Dimension 7 is generous to stiffen piece against milling distortion.

2. As cast

(a) 1 and 2 are combined — no brazing.

(b) Edge 3 is not needed; this reduces height of piece.

(c) 4 is cast to spherical radius.

(d) Channel 5 is cast.

(e) Gradual curve 9 replaces milled surface 6 and counterbore 8.

Result: Design is simpler and has greater structural continuity when cast.

Fig. 1—Machined and brazed ball joint simplified by precision investment casting.

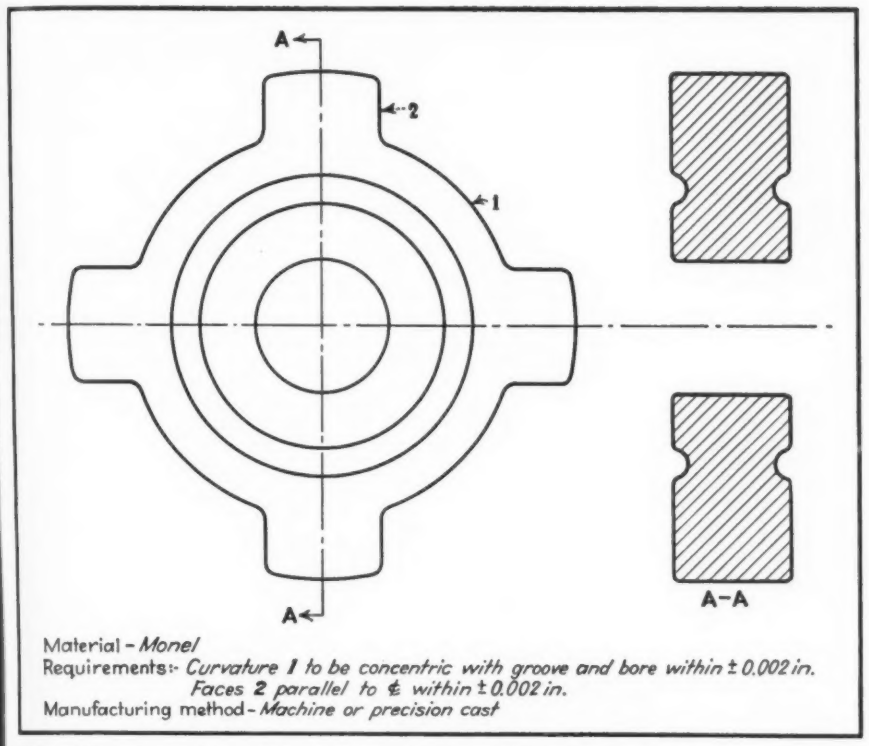

A
2
1
A
A–A
Material – Monel
Requirements:- Curvature 1 to be concentric with groove and bore within ± 0.002 in.
Faces 2 parallel to ℄ within ± 0.002 in.
Manufacturing method – Machine or precision cast

Fig. 2—Part formerly machined now made by precision investment casting with minor change in detail design. Grooves on both faces made casting cheaper than machining.

two parts that lent themselves to precision casting. Even here, machining might have been necessary if the part had been used in some other way, or allowable tolerances were closer.

HEAT TREATMENT. Some castings which formerly were cast in unmachinable alloys to get hardness and other physicals, now are cast in machinable ones, machined, and heat treated. Casters have found that precision investment castings after heat treatment have exactly the same physicals as the same alloys in wrought forms after the heat treatments. By special alloying to promote heat treatability, the castings may show better heat treated properties with no important sacrifices in machinability. This is one of the gains to be made by an open-minded study of alloys to be cast.

SURFACES. Depending upon the alloy and the design of the casting, precision investment castings may show surface flaws. Flaws include decarburization, pits, blisters, blemishes and scabs. They occur more often and more severely in alloys of high pouring temperatures, sluggish thermal conductances coupled with high specific heats, heavy surface segregations, and long hot plastic ranges. But since some are caused by alloy characteristics and others by human errors in the casting shops, no alloys are immune from them.

Decarburized surfaces can be recarburized. Scabs, blisters, blemishes and sometimes pits can be hand ground away. Ground areas will look different from shot blasted areas, unless the casting is shot blasted a second time after cleaning it up. But this also is true of the inescapable gate area or areas.

The problems of gate positions and areas are less with some alloys than others, but are greatly affected by casting designs and sizes. No alloy can make the gate position completely independent of casting design.

The gate may be removed by friction sawing or abrasive cut off wheels. This leaves some metal to be hand ground, machine ground, lathe cut or otherwise removed depending upon the accuracy desired at the gate position and machinability of alloy.

GENERAL FACTORS. All problems of precision investment casting increase with thicknesses of sections, dimensions of uninterrupted flat areas, and abruptnesses of transitions from thick to thin sections. These are the general design limitations on size and weight. There are no physical limitations on sizes that may be cast. The limitations are economic, and are, generally but not absolutely, seven inches on any dimension and six pounds in weight. Some casters like to make precision investment castings larger than this, but most casters will not go beyond these limitations.

Costs may be saved if a slight draft, usually 0.001 in./in., is allowed to get patterns out of molds. This rarely affects the accuracy of castings.

CONCLUSION. To get the best results from precision investment casting requires, first, open-minded but careful consideration of alloys. This method can cast any alloys which can be melted and poured into molds, but cannot cast all with equal ease. Far more options as to casting procedures are offered by this than by any other casting method, but the options can raise costs, and not all castings problems of alloys can be solved by them.

Second, a careful balance must be struck between contours and dimensional accuracies obtained by casting and those obtained by machining. Precision investment casting reduces machining problems, but machining also can reduce casting problems.

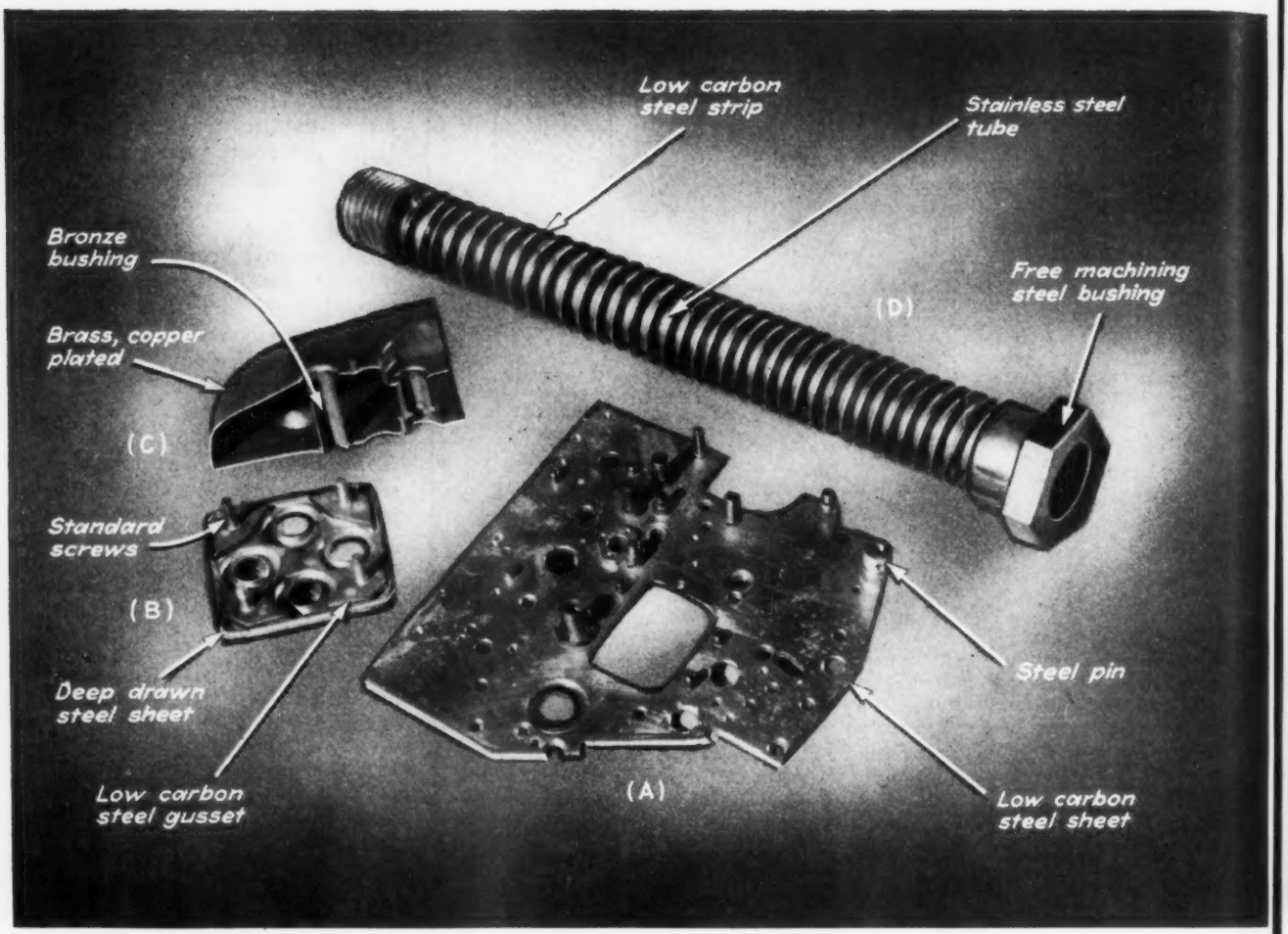
Third, an equally careful balance must be found between casting plus machining, and other secondary operations such as heat treating and grinding.

Fourth a common sense attitude must be taken about surfaces desired and methods of obtaining them.

Design factors such as avoiding abrupt transitions from heavy to light sections, using shrouds and braces to control warpage, and ribs and fillets to control heat, all work on principles familiar to sand casting. The difference is that in precision investment casting mold temperatures and mold permeability can be controlled better, resulting in higher strength walls and cores and more accurate cavities. This difference is only in degree. It never is absolute.

* * * *

WHILE PERFECTING the initial model of his sounding electro-magnetic telegraph in 1828, Joseph Henry noted the drop in current pressure produced by the mile long wire in his circuit. He reasoned that a secondary power source should be supplied at the point of operation to avoid the line loss and attendant loss in work availability. He decided to control the operation of a switch on this secondary power source and thereby controlled the final operation. He designed an electro-magnetic switch for this purpose and so was the first to use a "relay."



FURNACE BRAZING formed these intricate assemblies quickly and inexpensively by joining the many individual parts of different materials. (A) Computor side plates fabricated from 18 separate parts; (B) rectifier lid made from 10 parts; (C) section of one-fourth of steam iron, 9 parts; (D) resistor case, 4 parts. Furnace brazing is good for mass production.

How Brazing Methods Affect

Comparison of different techniques of torch, resistance, bath, furnace, and induction brazing. Method used affects selection of materials, design of details, and properties of brazed joints.

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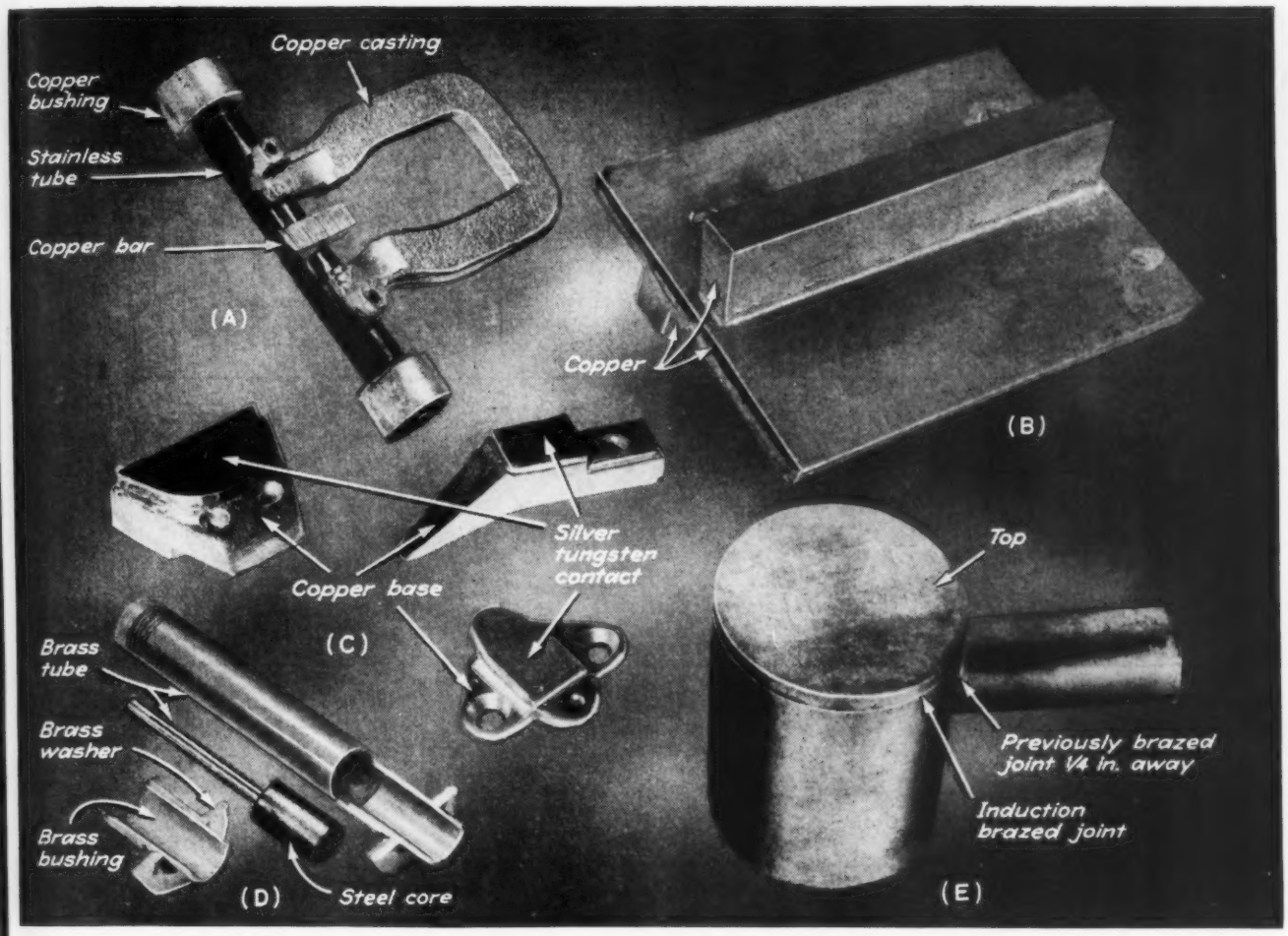
Materials Engineers, Westinghouse Electric Corporation

FUNDAMENTALLY, brazing is the oxide-free bonding of similar or dissimilar metals by a filler alloy that has a lower melting point than that of the metals joined. Basic advantages of brazed joints include uniformly high strength under different load conditions, relatively low distortion and residual stress concentration, and the inherent possibility of high production rates. By properly designing parts for brazing into assemblies simplified and lower cost fabrication is possible. This is nearly always true when the design is such that many parts can be placed in a furnace, for example, and brazed at the same time.

In addition to these basic advantages, brazed joints have other useful characteristics. They are highly resistant to vibrating and impact loads. Joints maintain their strength at high temperature. Because of the deep penetration of the brazing alloy into the minute clearances, joints are pressure tight. Thermal and electrical conductivity is high. Simultaneous hardening of steel, especially of air hardening types, can be obtained when joints are brazed in a furnace or salt bath. If desirable, parts can be assembled, then brazed in an atmosphere that prevents decarburization, and emerge completely finished, hardened, and ready for tempering. Because of the protective atmosphere, surfaces are clean and bright thus saving the usual cleaning and pickling expense.

Characteristics of the brazing material and the type of brazing method has an effect on the properties of the joint. Two essential requirements of a brazing metal or alloy are high fluidity and ability to wet or alloy with the metals to be joined when at the brazing temperature. For proper wetting, both the metals joined and the molten brazing material must be free of oxides when the brazing temperature is reached. Oxides are prevented from forming throughout heating by



FIVE MORE BRAZING METHODS. (A) Five parts of flow switch joined by torch brazing. (B) Relatively massive parts of shielding base brazed by radiant gas burner. (C) Silver tungsten contacts attached by resistance brazing. (D) Thrust tube and core brazed in salt bath; tube is sectioned. (E) Induction heating brazed on top without loosening a nearby joint.

Design of Details

(1) a reducing atmosphere, or (2) the addition of flux to the joint, or (3) the exclusion of oxygen during heating by immersion in a molten bath. Silver brazing, for example, uses any of these methods. Copper brazing is commonly done in furnaces containing controlled reducing atmospheres. But several recent applications use high temperature salt baths or induction heating for brazing copper with a flux or a reducing atmosphere to prevent oxidation.

Six Brazing Techniques

The following six basic types of brazing are compared in Table I.

HAND TORCH. Hand torch brazing is the best known method and is widely used because of low cost of equipment and its flexibility. The work is cleaned, flux added, and assembled; if necessary the work is supported in a fixture. An oxy-acetylene, oxy-hydrogen, air-acetylene, or air-gas torch is used with the flame adjusted for a reducing effect. The torch flame is moved constantly to prevent local overheating. Usually, insulating brick around the work speeds the heating. When the joint area is at the right temperature as judged by eye, brazing alloy is fed into the joint, melts and is drawn into the opening by capillary attraction until the joint is filled. Excess alloy forms a fillet.

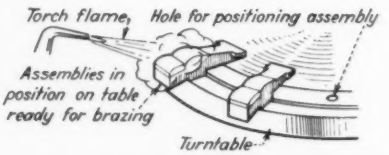
AUTOMATIC TORCH. Automatic torch brazing often uses an automatic conveyor that moves the work (1) into the fixed flames from radiant gas burners for a predetermined interval of time, then (2) into the cooling position. For circular joints the fixture usually rotates the work while it is in the hot zone until it is brazed and then moves it out to cool. With the cycle set, this technique gives high production with unskilled operators.

DIRECT AND CARBON RESISTANCE. These methods are similar types of brazing but differ in principle. In the direct resistance brazing the joint is heated by its own resistance to the passage of electric current. For example, the pieces to be brazed are mounted between the electrodes of a spot or butt welding machine. In carbon resistance brazing, current flowing through two carbon electrodes produces heat in the carbon that is transferred by thermal conduction to the parts to be brazed.

In both methods the brazing alloy in foil form is placed between the two pieces to be joined; heat and pressure is applied until the brazing alloy flows and forms a fillet. The current is interrupted but pressure is maintained until the brazing metal has solidified. A distinct advantage of the resist-

Table I—Comparison of Basic Methods of Brazing

TORCH. Heat applied by hand torch burning oxygen or air with acetylene, hydrogen, or methane.

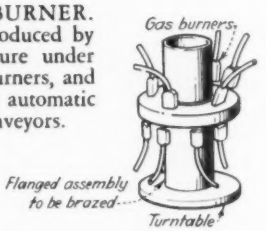


ADVANTAGES: Low cost of equipment; heating can be localized; applicable for many types of assemblies.

LIMITATIONS: Requires skilled operators; relatively slow; can not be used for copper brazing; temperature control is difficult. Assemblies with multiple or inaccessible joints can not be brazed; work will oxidize; localized heating may cause distortion.

APPLICATIONS: Silver and phos-copper brazing assemblies requiring extensive fixturing, or where self jigging is impractical.

RADIANT GAS BURNER. Concentrated heat, produced by burning gas-air mixture under pressure in ceramic burners, and applied to work on automatic indexing tables or conveyors.

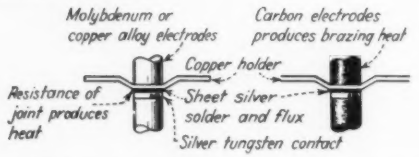


ADVANTAGES: Localized, rapid heating; controlled heat makes automatic setups practicable for high production; unskilled operators can be used.

LIMITATIONS: Equipment more costly than torch brazing. Copper brazing not possible; work oxidizes; some distortion possible. Multiple or inaccessible joints may be impractical to braze because of excessive oxidation. Exact temperature control difficult.

APPLICATIONS: Silver and phos-copper brazing, especially for mass production; particularly when assembly has massive parts that need not be heated.

RESISTANCE. Assembly heated between electrodes by (1) its own resistance to passage of current or (2) by conduction of heat generated in carbon electrodes.

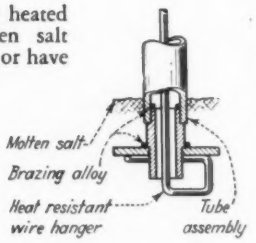

Molybdenum or copper alloy electrodes
Carbon electrodes produces brazing heat
Copper holder
Resistance of joint produces heat
Sheet silver solder and flux
Silver tungsten contact

ADVANTAGES: Rapid localized heating. Moderate production rate. Extremely effective for making such things as long seam brazes.

LIMITATIONS: Temperature control difficult; individual handling necessary; copper brazing not possible, distortion possible; assemblies limited in size.

APPLICATIONS: Silver and phos-copper brazing of small parts, such as silver contacts to copper holders. Used where combination of heat and pressure are desirable to insure good brazes.

SALT BATH. Assembly heated by immersion in molten salt bath; bath can be neutral or have fluxing action.

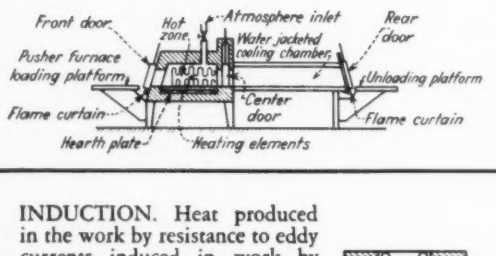


ADVANTAGES: Rapid heating, which can be localized in some applications. Temperature can be controlled. Flux not required for some applications. Copper brazing is possible with high temperature salt baths.

LIMITATIONS: Undesirable carryover of salt; necessity for thorough washing to remove salt; usually some oxidation during cooling; danger of explosions from wet work; fixtures required.

ADVANTAGES: Aluminum brazing, silver and phos-copper brazing; and copper brazing to a limited extent. For assemblies that require rapid heating and lend themselves to suspension in fixtures.

FURNACE. Heated by furnace in presence of reducing atmosphere. Furnace can be heated by resistance elements, radiant tubes, globars or by gas if it is used.

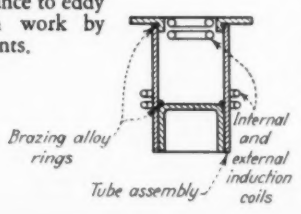


ADVANTAGES: Good for mass production. Accurate control of temperature; uniform heating reduces distortion; no residual stresses. Copper, silver, or phos-copper brazing possible; bright surfaces; control of carburization or decarburization.

LIMITATIONS: Localized heating not possible. Requires design of self positioning of components or suitable fixturing.

APPLICATIONS: Mass production brazing in which design of joints permit self positioning or fixturing without excessive added weight. Widely used for copper brazing; often economical for silver brazing in mass production, multiple, or inaccessible joints.

INDUCTION. Heat produced in the work by resistance to eddy currents induced in work by high frequency currents.



ADVANTAGES: Mass production. Localized, rapid heating.

LIMITATIONS: Copper brazing not feasible; possibility of distortion because of localized heating; some oxidation; temperature sometimes difficult to control accurately.

APPLICATIONS: Mass production silver brazing where parts lend themselves to assembly line treatment. Applications where joint is not too deep or components are not too heavy.

ance brazing methods is that flux is squeezed out of the joint and intimate contact is maintained between the two parts being bonded. Limitations include the fact that the assemblies must be mounted between the electrodes of a welding machine, and that the electrodes require frequent cleaning.

SALT BATH. Molten salt baths, used for brazing parts are usually neutral, although fluxing agents can be included to dissolve oxides. If necessary to prevent oxidation the parts are fluxed and the silver alloy is placed at or in the joints. When the flux is dry, (to avoid the danger of an explosion) the assembly in a suitable jig or hanger is immersed in the molten salt. Since the temperature of the salt bath is kept higher than the top of the melting range of the brazing material good brazing is assured. Advantages include control of temperature, and avoidance of carburization, decarburization, or oxidation when steel is being brazed. Main disadvantages are the inconvenience of using molten salt and the possibility of the metal being etched by contaminated salt.

ATMOSPHERE FURNACE. Furnace brazing is extremely versatile and widely used for copper and silver brazing of all kinds of parts. The method uses a gastight furnace with a gastight cooling chamber and doors for separating different areas in the pusher type furnace, for example. A conveyor furnace has purging chambers at the front and rear with doors adjusted just high enough for movement of the assembly.

A reducing atmosphere such as hydrogen or dissociated ammonia in the furnace and cooling chamber is maintained above atmospheric pressure inside the furnace and keeps out air or water vapor. Formation of oxides is inhibited, and if any oxides reach the hot zone they are reduced. Thus the molten brazing metal flows smoothly and wets uniformly. In copper brazing, no flux is used unless the steels being joined are high in alloys such as chromium, aluminum, or manganese. In silver brazing, flux is generally applied unless (1) the assembly consists of materials whose oxides are easily reduced in the furnace atmosphere (such as copper, silver, or nickel) and (2) the brazing alloy contains no zinc or cadmium.

INDUCTION. In this method, heat is generated within the parts to be brazed. The parts are placed near coils carrying high frequency current which induce eddy currents in the metal parts to be brazed. Resistance of the metal to the flow of eddy currents produces the heat for brazing. Since the heat is generated in the surface skin, the heating and flow of the filler metal is rapid and little change occurs in the parent metal.

For the right shape and size of parts, indexing tables or conveyor belts can be used for rapid joining. Such applications commonly use silver brazing. Copper brazing can be used if the longer time and higher temperatures occur in a reducing atmosphere that prevents oxidation.

Effect of Materials

The selection of the most economical design is concerned not only with the method of brazing but also with the kind of materials such as aluminum, copper, low carbon, or high alloy steels. This influences the brazing material and preliminary treatment. For example, since the brazing alloy must have a lower melting point than the metals to be bonded, the softening or hardening of the parts may have a direct effect upon their performance in service. Flux is required for all methods except furnace brazing. The possible attack of the metal by the flux or attendant difficulties in removing flux from recesses, may make furnace brazing desirable.

LOW CARBON STEEL. Low carbon steel can be brazed by any of the six methods. It is best and most conveniently joined by furnace brazing using copper, but torch or induction brazing with silver alloys is widely used. Copper brazing in controlled atmosphere furnaces produces strong, clean joints; and the part requires no cleaning or other treatment before plating or direct use in an assembly. Since the brazed parts are heated to 1,100 C they are fully annealed and grain structure may be coarsened, which in turn weakens the assembly. But with copper brazing, the assembly can be subsequently heat-treated without danger of impairing the joint. This is particularly significant in higher carbon steels where subsequent heat treatment may be desirable.

Silver brazing of low carbon steels by induction heating requires the use of flux, but the heated zone is a minimum. Metal immediately adjacent to the joint is softened considerably, but later heat-treatments cannot be used except with higher melting brazing alloys.

MEDIUM AND HIGH CARBON STEELS. These will decarburize during furnace brazing unless (1) an atmosphere with sufficiently high carbon potential (such as Endogas) is used, or (2) the material is protected by copper plating. Higher carbon steels usually are used for designs requiring higher strength so copper brazing is desirable. Pieces so brazed can be heat-treated in any normal manner.

Assemblies to be subsequently hardened also can be brazed in a salt bath, using a silver alloy of slightly higher melting point than the upper critical temperature. After the brazing metal solidifies, the assembly is immediately quenched.

Phosphorus-bearing brazing alloys such as Phos-copper or Sil-fos should not be used with ferrous metals since (1) they form poor joints and (2) the phosphorus will form brittle compounds with the iron.

HIGH ALLOYS STEELS OR CHROMIUM-NICKLE ALLOYS. These materials can be copper or silver brazed in standard-type furnaces if flux dissolves the oxides formed. Such an assembly is usually discolored and requires as much cleaning and pickling as those made by torch or induction heating. A gastight muffle furnace precludes the occurrence of oxidation of the work if dry atmospheres are used; also such a furnace can simultaneously braze and harden dies made of tool steel.

CAST IRON. Cast iron is best brazed in furnaces; but it can be done by induction or torch heating. High silicon and carbon in the cast iron makes good wetting more difficult. A preliminary treatment of the iron by oxidation and subsequent reduction of the surface, or a Kolene bath treatment, usually assures good bonding. Flux assists in the reduction of the oxides both when copper and silver alloys are used.

COPPER AND ITS ALLOYS. These can be brazed by any of the six methods, using either phosphorous-copper or silver alloys. The method usually depends on the number and size of the pieces to be assembled and the mass of metal involved. Torch brazing is slow but is the most economical for few assemblies. Also salt bath brazing is adaptable to assembling in small quantities but it is inconvenient and suitable only in specific instances. Radiant burner and induction heating methods permit the observation of the formation of the fillet and correction of misaligned pieces, which is not possible in furnace brazing. They require a minimum of equipment, providing high frequency generators are available. Resistance brazing involves the use of relatively expensive equipment and is applicable only where the pieces

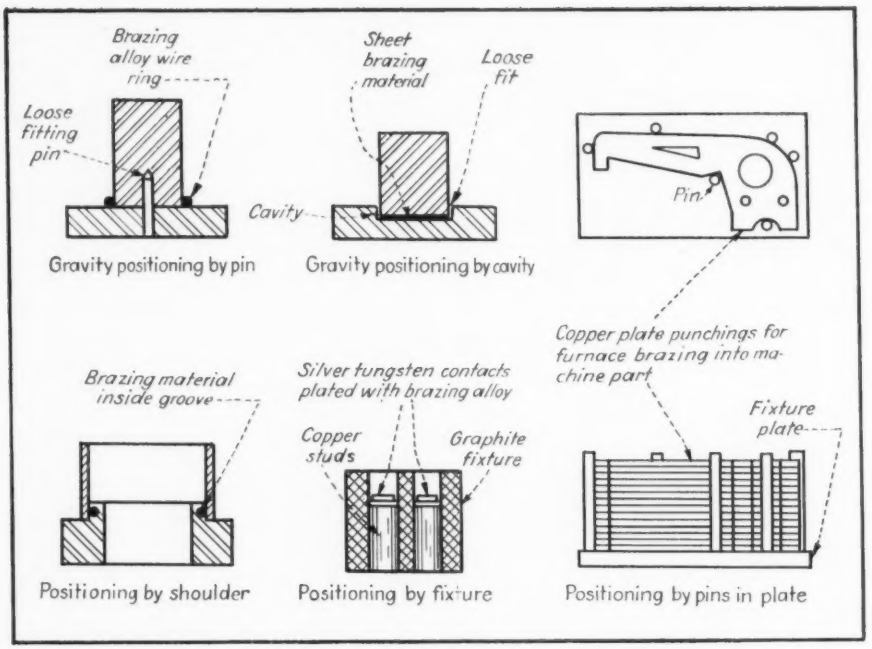


Fig. 1—Attention to design details of parts to be brazed often can simplify fabrication. During bonding, precise positioning of each of the parts always is essential.

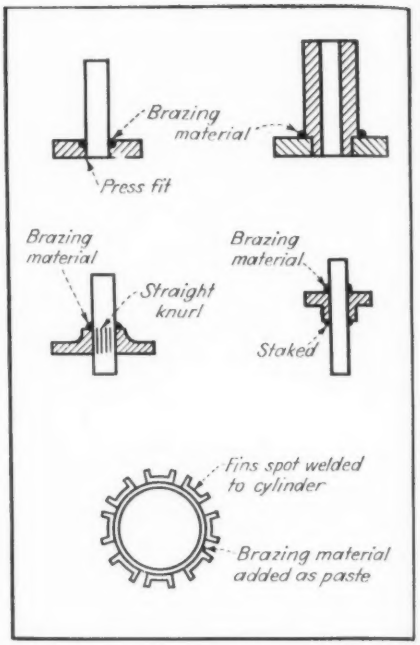


Fig. 2—Five commonly used designs for brazing pin or tube and hole type units.

can be held between the electrodes.

Furnace brazing produces uniformly good joints in assemblies consisting of copper and its alloys. Copper and bronze can be furnace brazed in atmosphere without flux by using brazing alloys free of zinc or cadmium. Brass can be brazed in this manner if it is copper plated before brazing. Copper and high copper alloys can be successfully brazed with Phos-Copper or Sil-fos by any of the six brazing methods.

ALUMINUM BRONZES. These require the use of very active flux to remove oxides. They can be brazed without flux in atmosphere furnaces, if they are first copper plated.

NICKEL AND MONEL. These can be joined by any of the methods, but the low temperature silver solders are recommended to prevent intergranular attack.

For proper brazing results, cleanliness and proper positioning of the individual parts of an assembly are essential. Removal of oxides, dirt, grease and oil is necessary for complete cohesion and penetration of the brazing material throughout the joint. When flux protects against oxidation during heating, it must effectively prevent the oxidizing elements in the air from reaching the surfaces of the joint. But when a reducing atmosphere furnishes protection, little additional protection of the joint area is required; the main work of the atmosphere is in reducing oxides present.

Removal of oxides and tarnish before brazing can be done mechanically by filing, grinding, tumbling, or shot blasting. Sandblasting or wire brushing are not recommended. With sand blasting, any particles of sand retained by the surface interfere with the flow of brazing material. Wire brushing sometimes smears metal over the oxide rather than removing it. Pickling is used when there is no clean machined surface.

Grease and oil is removed best by degreasing. Its removal is important because during the rapid heating of the joint area the grease or oil usually is not burned entirely away. It leaves a carbonaceous residue that may interfere seriously with the flow of the brazing alloy.

Correct alignment and relationship between the individual parts of an assembly during bonding is necessary. Self aligning fits maintained by gravity include protuberances or grooves in one or all of the parts or by utilizing loose pins as shown in Fig. 1. Generally, fixture material must be heat resistant and resist wetting by the brazing alloys. For dimensional accuracy, the fixture material may have to match the rate of expansion and contraction of the assembly. Many materials are available such as carbon or the stainless steels and various rates of expansion and contracting can be selected from the alloys of chromium. If a particular thickness of brazing alloy is desired in a gravity assembly, shims can be used. The shims should be of a material that is readily wet by the brazing alloy but that will not be dissolved.

In applying brazing materials, the alloy in sheet form can be preplaced

Table II—Composition of Commonly Used Brazing Alloys

Designation	Composition, percent					Melting Range Temperature	
	Cu	Ag	Zn	Cd	P	C	F
Copper	99+					1,083	1,982
Cu-Ag	50	50				778–850	1,432–1,562
Easy Flo	15.5	50	16.5	18		627–734	1,160–1,173
Phos Copper	93				7	704–800	1,300–1,472
Eutectic	28	72				778	1,432
ETX	34	50	16			695–775	1,284–1,427
Sil-Fos	80	15			5	643–704	1,190–1,300

inside the joint or in wire form it can be placed at the outer edge of the joint. With torch brazing the alloy can be fed into the joint after the work reaches brazing temperature. Sometimes the filler material can be buried in cavities within the joint; when the assembly reaches brazing temperature the molten alloy is drawn from the reservoir into the joint by capillary attraction. When a cavity is designed for this method, vent holes should allow entrapped air to escape, especially for furnace brazing.

A common method of joining uses a hole with a pin or tube as shown in Fig. 2. Usually, simply making the parts a slight press fit maintains their position. Sometimes a straight knurl on the male piece simplifies design and avoids higher costs inherent in other methods. Other means include peening of the hole or pin and staking, swaging, or hot or cold riveting of the pin.

In addition for positioning of tube or bushing assemblies, they can be spun, crimped or expanded into place. Often it is simpler to design the male member of this type assembly with a shoulder to provide positioning. Design requirements to prevent stoppage of the molten filler metal are a minimum fillet at the base of the shoulder and no countersink on the hole.

Oftentimes tack welding can be used; or if the material is thin enough, spot welding. Older methods of joining such as screwing, pinning or riveting are used occasionally.

Often in brazing of sheet metal assemblies, lap or interlocking joints are used, and the joint provides proper positioning. If not, try spot welding, peening or screwing.

For best results, wetting and bonding characteristics of the surface should be considered. A smooth highly polished surface is not conducive to creeping of the molten brazing material. This is because the surface attraction of the metal fails to overcome the surface tension of the liquid copper or silver alloy. But a clean and slightly roughened surface, such as obtained by shot blasting, pickling, or machining causes rapid and uniform flow of the brazing alloy over the surface of the steel. Thus judicious design can control the creep of the joining material.

Other means for preventing undue flow of the material include: (1) Use of grooves or ledges at appropriate points; (2) imbedding brazing alloy in concealed grooves in the joint; (3) decrease of the hydrogen content of the atmosphere; (4) use of the minimum amount of brazing material compatible with the good quality; or (5) use of painted on barriers of refractory powders in paste form such as chromium oxide, magnesium oxide or aluminum oxide. By proper application of the localized heating, in torch, dip or resistance, excess flow from the joint is less troublesome than when using one of the other methods.

Forged surfaces are highly conducive to superfluous creep. When they are parts of assemblies, it is often better to let the brazing alloy flow freely and remove the excess by grinding, scraping, chemicals, or electrolytic stripping. For copper alloys, sodium cyanide or chromic acid solutions are effective stripping agents.

The type of alloy that is used as a filler metal, as well as its form and placement in the assembly, is important. The choice of alloy depends on such factors as its melting point compared to that of the assembly components and the absence of any materials in the alloy that might harm parts of the assembly. The analysis and melting range for some brazing materials are shown in Table II.

Factors influencing the selection of the alloy, its form, and whether it is preplaced or fed into the joint are determined by whether for example: (1) The part is to be torch brazed where feeding is possible or furnace brazed where it is not; (2) counterbores, concealed grooves, or cavities are permissible in the assembly thus enabling use of wire, sheet or slugs of brazing material; (3) the flow of the alloy into the joint will be aided by gravity or whether only capillary attraction is used. In the designs that make it difficult to apply the alloy where wanted, pastes of powdered brazing metal, or plating with the brazing metal, or even spraying of the metal can be used.

Properties of Brazed Joints

For low carbon low alloy steel where the parts to be brazed are sufficient in mass to prevent changes in clearance during the brazing cycle, the shear strength of the joint decreases as the clearance increases. Average values for common fits are shown in Fig. 3(A). Recommended fits for copper brazed joints should be no greater than 0.001 in. clearance to 0.002 in interference. But with hardened and tempered higher strength steels, values are much higher, averaging 55,000 psi in shear when clearance is within the limits specified.

Because of the lower fluidity of silver alloys at the brazing temperature, interference fits are not recommended. But even with the prescribed clearance of from 0.001 to 0.003, the shear strength values of silver brazed joints are quite high being between 24,000 and 40,000 psi. As shown in Fig. 3(B), strength increases with decreasing clearance.

Generally, as shown in Fig. 3(C), the average tensile strength of a brazed joint is approximately twice the shear strength.

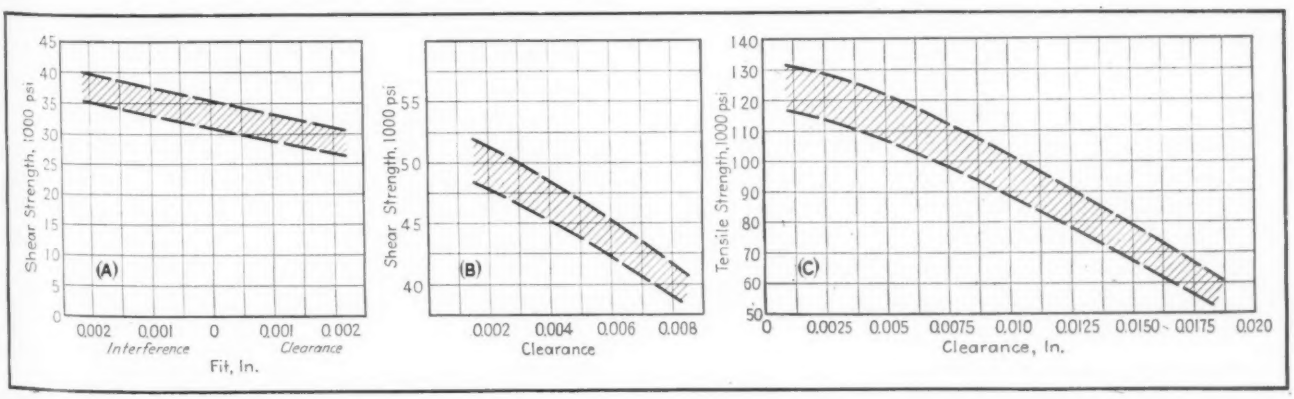
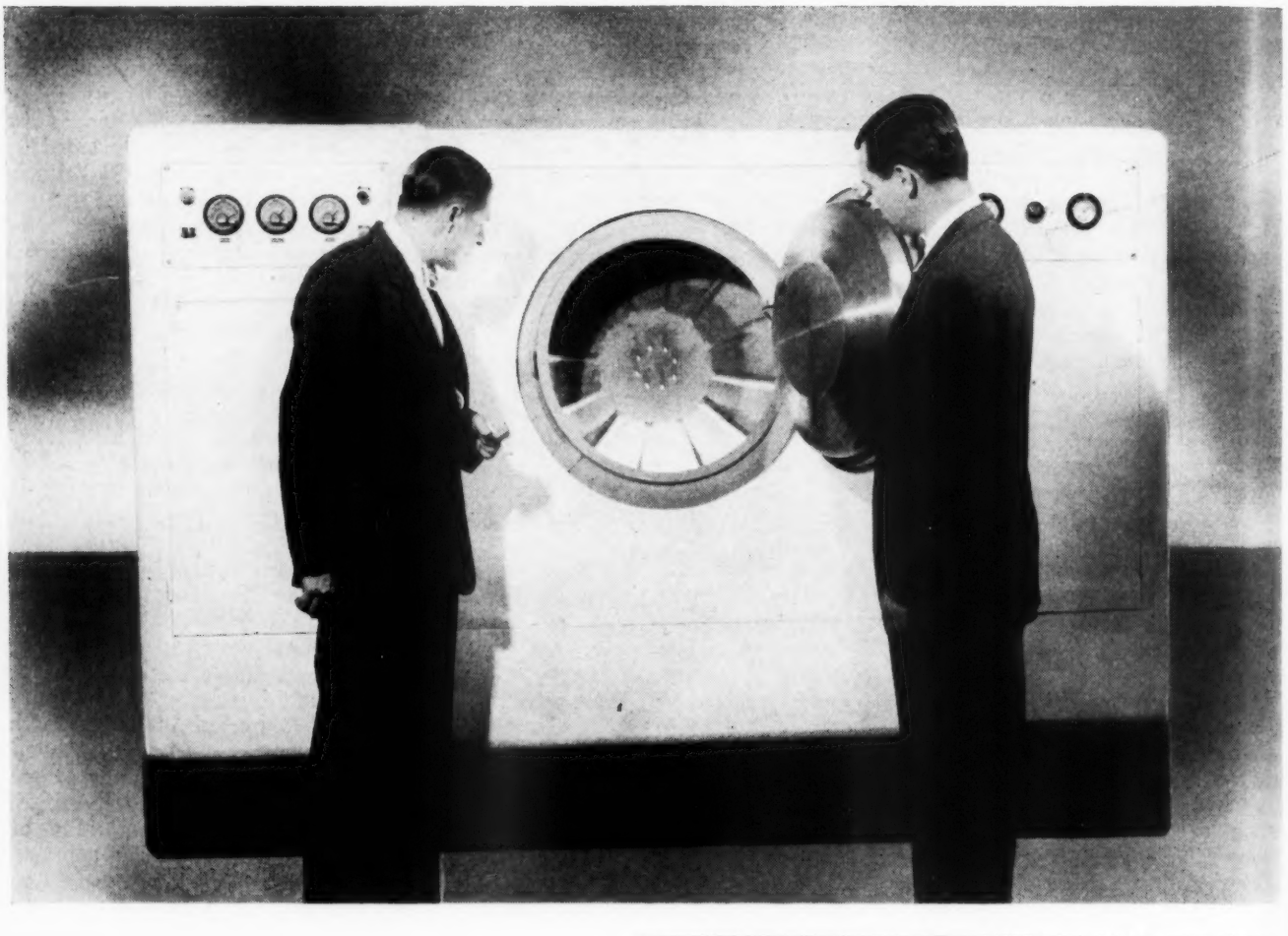
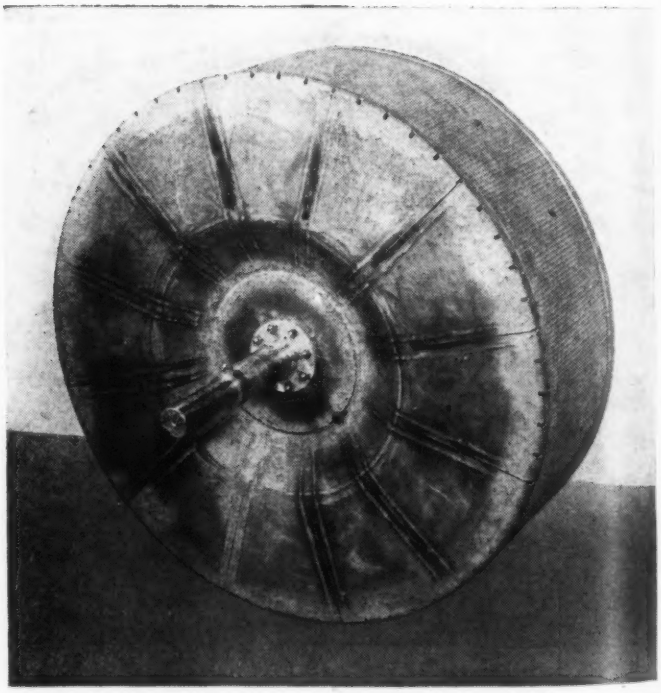


Fig. 3—Strength comparisons. (A) Relationship of shear strength to clearance for copper brazed joints. (B) Relationship of shear strength to clearance for silver brazed AISI E4337 steel. (C) Relationship of tensile strength to clearance for butt joints in stainless steel of 160,000 psi tensile strength.

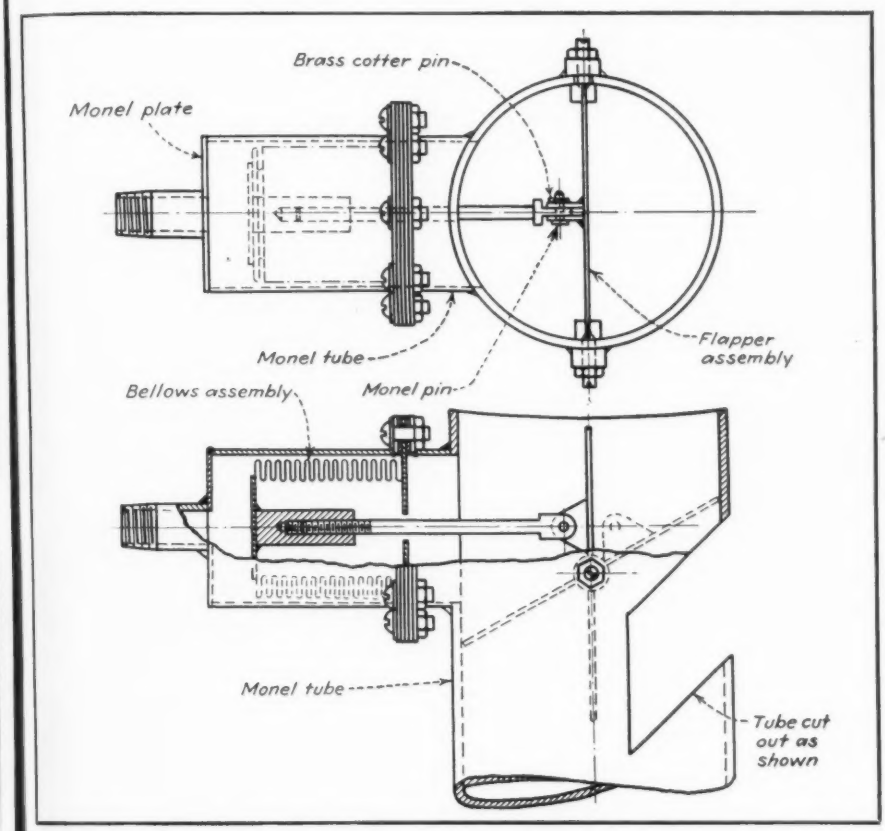


Automatic Dry Cleaning Machine

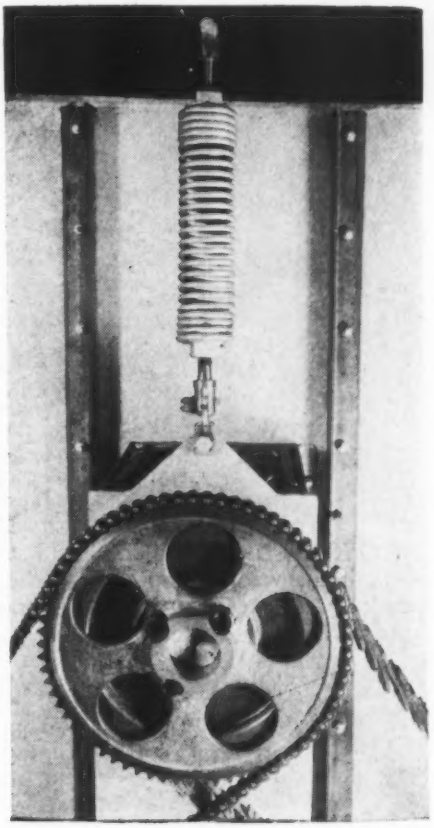
Operation of this dry cleaning machine, designed by George E. Wells, Inc., St. Louis, is fully automatic. Only the timer for the 5 to 15 min. "wash" phase has manual adjustment. Five min. "extract" phase and 6 min. "dry" phase are fixed. Frame is 16 ga welded steel consisting of 3 in. square hollow corner posts and 3 in. by 6 in. hollow horizontal beams. Hinges, bearings and valves are made of copper to resist wear caused by the corrosive action of synthetic solvents. A safety latch mechanism locks door while basket is in operation. Latch releases at a set time interval after power is turned off or the cycle ends. Cabinet has six hinged and five buttoned panels for accessibility before and after unit assembly. Flexible synthetic hose purchased complete with fittings comprises the plumbing. Exterior finish is baked-on enamel.



WASHING BASKET is a monel metal cylinder 40 inches in diameter and 14 inches deep. It is made of a front and rear stamping and perforated wrapper. Shaft is bolted to basket.



BUTTERFLY VALVE in 4 in. dia washer drain operates automatically. It is actuated by a linkage connected to a 2 in. dia corrugated bellows that is subjected to output pressure of the solvent pump. When pump operates, bellows compresses and valve closes causing solvent to rise in tank to level of overflow drain. When pump stops bellows releases and valve opens, thus draining tank.



THREE SPRINGS, located at the centroid of the mass, suspend the pedestal that carries the drive motors, blowers, washer tank and basket at an angle of 15 deg with the frame.

OPERATING CYCLE

(1) Fill basket with 40 lb clothes.

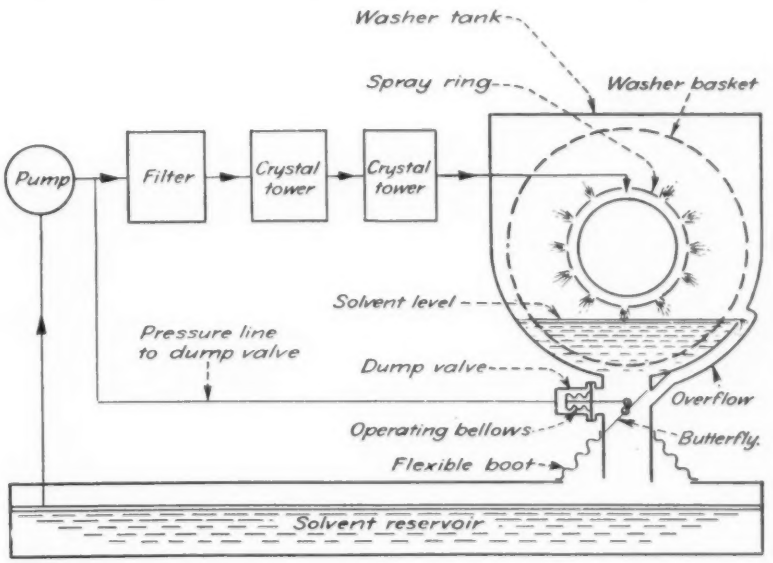
(2) Set "wash" timer for from 5 to 15 min. as desired.

(3) Start "wash" cycle by operating pushbutton control.
Low speed gearhead ½ hp motor turns basket at 36 rpm through overrunning clutch and chain drive. Turbine pump, driven by a ½ hp motor, supplies solvent to washer tank at 18 gpm.

(4) Automatic "extract" phase – 3 min.
Pump and low speed motor stop. High speed 1½ hp motor turns basket at 600 rpm through overrunning clutch and belt drive. Butterfly valve dumps solvent into reservoir.

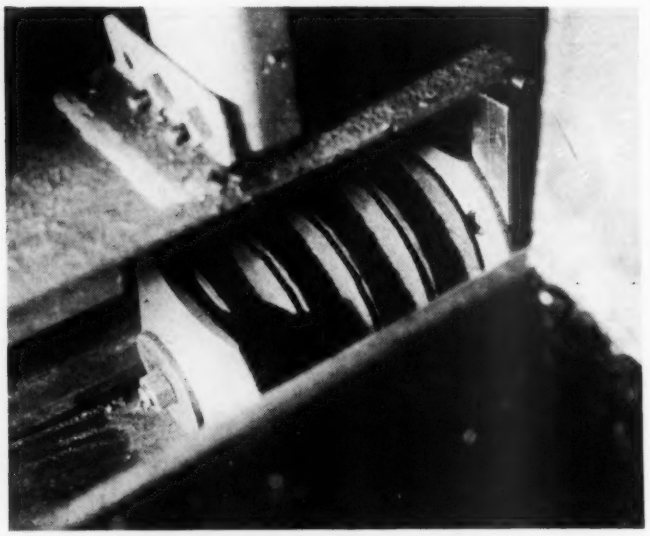
(5) Automatic "dry" phase – 6 min.
High speed motor de-energized. Disk brake on high speed motor slows basket to 36 rpm and low speed motor continues to turn basket. Centrifugal pump, driven by a ¼ hp motor, delivers 325 cfm of air to aerate dampened clothing.

(6) End Cycle
Basket drive motor and blower motor stop. Red light flashes on panel.

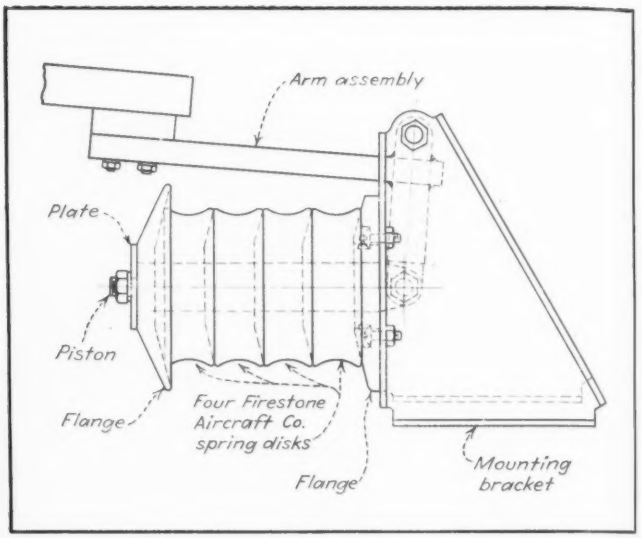


OPERATING CYCLE and flow of solvent are shown. Interior of storage tank, filter, washer and crystal tank have a zinc spray coating to resist corrosion from the solvent, which is either carbon tetrachloride or perchlorethylene. Reservoir tank is baffled and screened to mechanically filtrate water and solids from the solvent before it enters the pump.

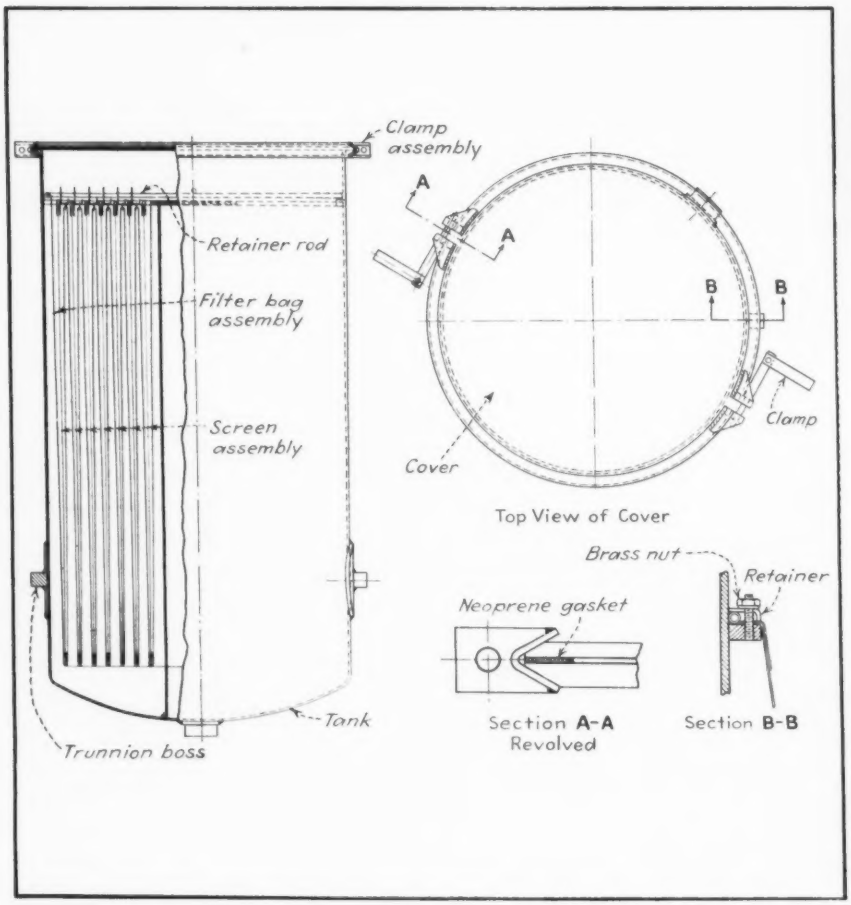
Dry Cleaner (continued)



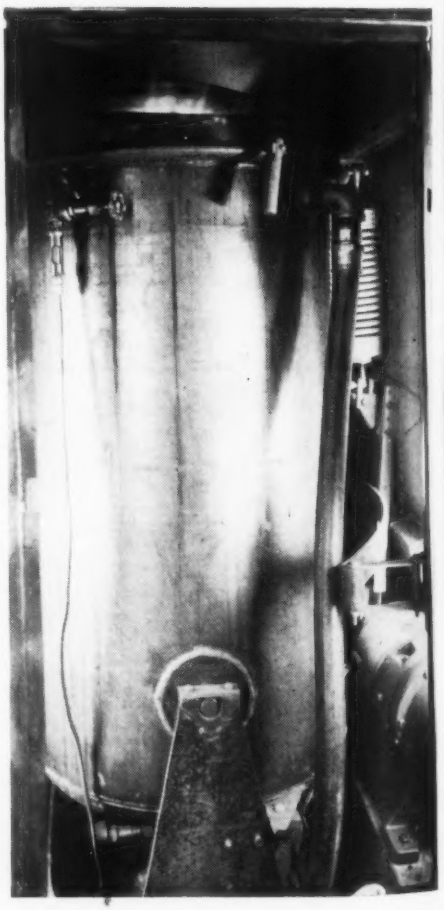
TWO RUBBER DISK SNUBBERS at the bottom are used to limit the vertical amplitude of the motion of the suspended washer unit assembly. Three leaf spring snubbers are provided at the bottom, sides and back of the mass.



BOTTOM SNUBBERS consist of a series of rubber spring disks that are compressed by the suspended unit through an arm assembly. Disks are mounted on the piston shaft by a nut and plate assembly. Arm assembly is welded.



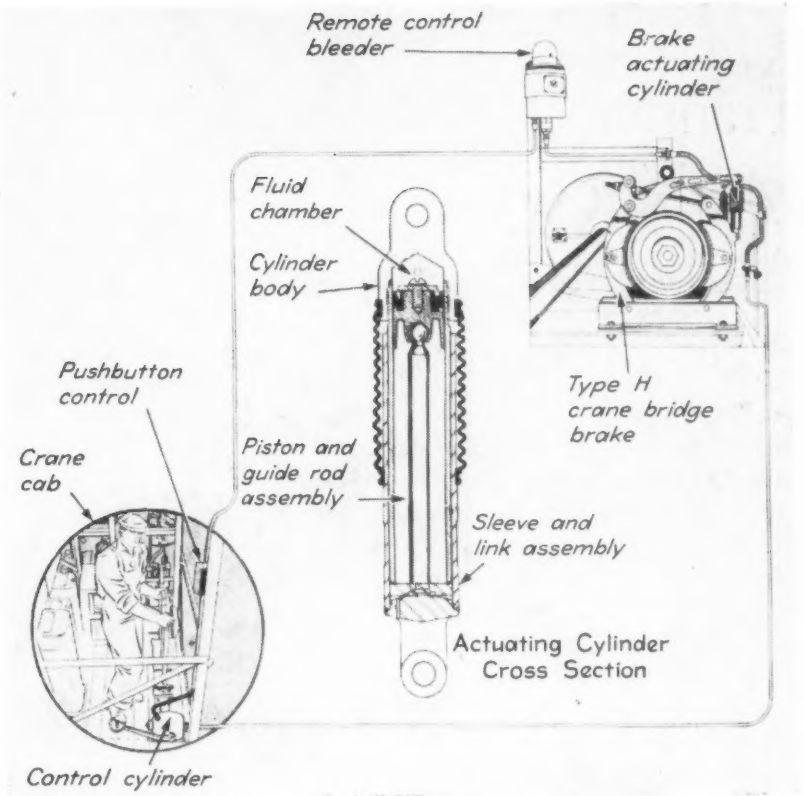
FILTER CROSS-SECTION shows the filter bag and circular wire screen separators. Bag is duck material that is coated with filter powder. It is 40 ft long and has an approximate area of 141 sq ft. Cover of the unit has a quick release clamp, and is made in two halves to facilitate removal of filter unit. Solvent is forced up through the filter. A lever control, which drops 1 qt of filter powder in the storage tank near the pump, is provided.



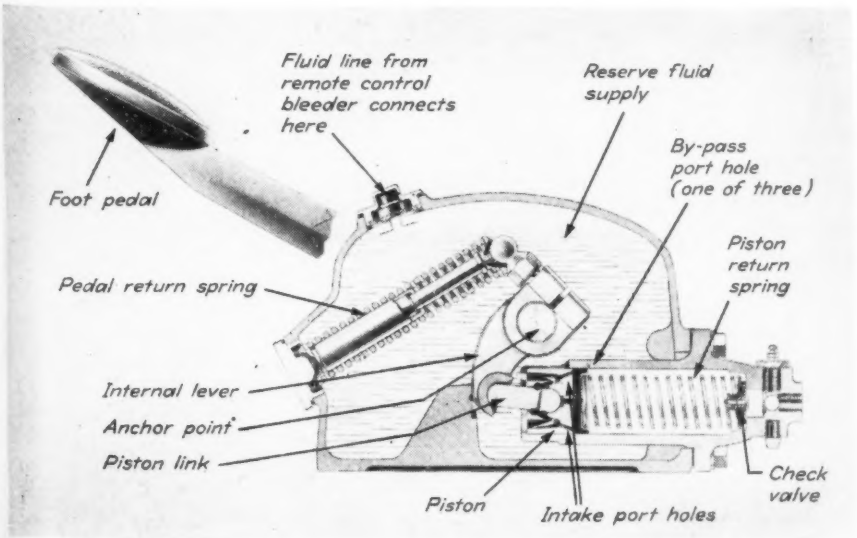
FILTER TANK is trunnion mounted to permit it to be tilted to a horizontal position for draining and cleaning the filter bag. One of the springs supporting the washer tank assembly is shown at the right of the tank.

Remote Control Hydraulic System For Crane Bridge Brake Operation

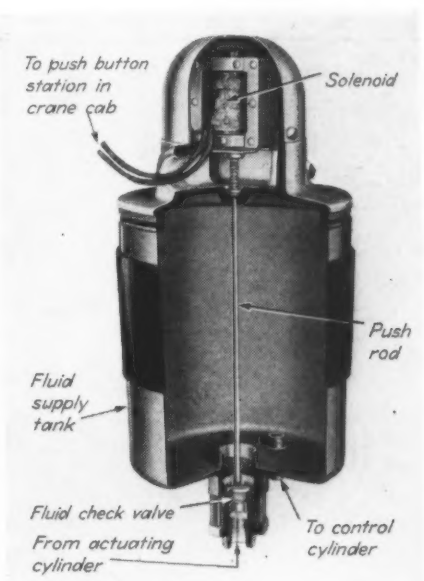
By adding a remote control bleeder unit to a crane bridge hydraulic brake system, the operator in the cab is able to remove air from the system at will. Other advantages of this remote control bleeder unit are the ability to install hydraulic brakes above their control cylinder and the prevention of air from entering fluid lines where temperatures change. Bleeder unit is mounted close to brake and at highest point in the system. System components are manufactured by the Wagner Electric Corp., St. Louis, Mo.



HYDRAULIC CIRCUIT shows the control cylinder and bleeder pushbutton control in the crane cab. Actuating cylinder is a telescoping type that is mounted on one of the brake shoes. Type H brakes have shoes that are made in sizes of 10 by 4 in., 14 by 6 in. and 18 by 8 inches.



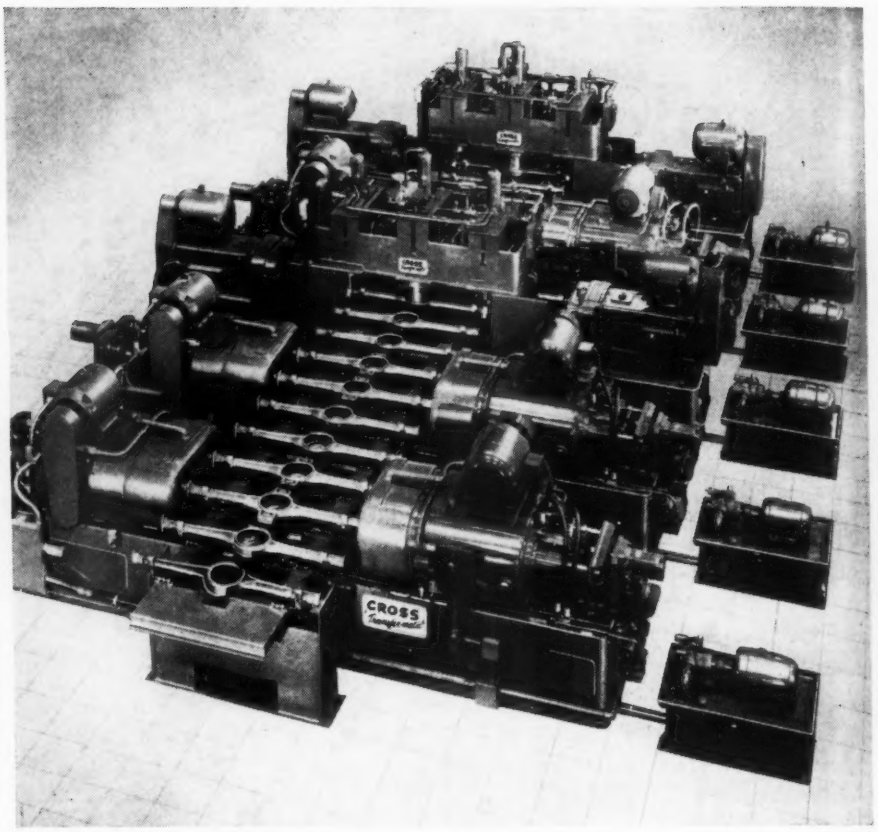
CONTROL CYLINDER in crane cab is pedal operated. Check valve retains pressure of from 8 to 12 psi in line and prevents fluid from draining back into cylinder. When foot pedal is quickly released, the fast return of the piston cup by the return spring, and the slower return of the fluid from the actuating cylinder, causes a vacuum in the control cylinder barrel. This vacuum pulls additional fluid from the reserve supply though piston intake port holes past lip of piston cup and supercharges the system. As return spring forces foot pedal back to release position, piston return spring pushes piston back until lip of cup passes the by-pass port holes through which surplus fluid escapes to normalize system pressure. 65 psi pressure is required to operate brake.



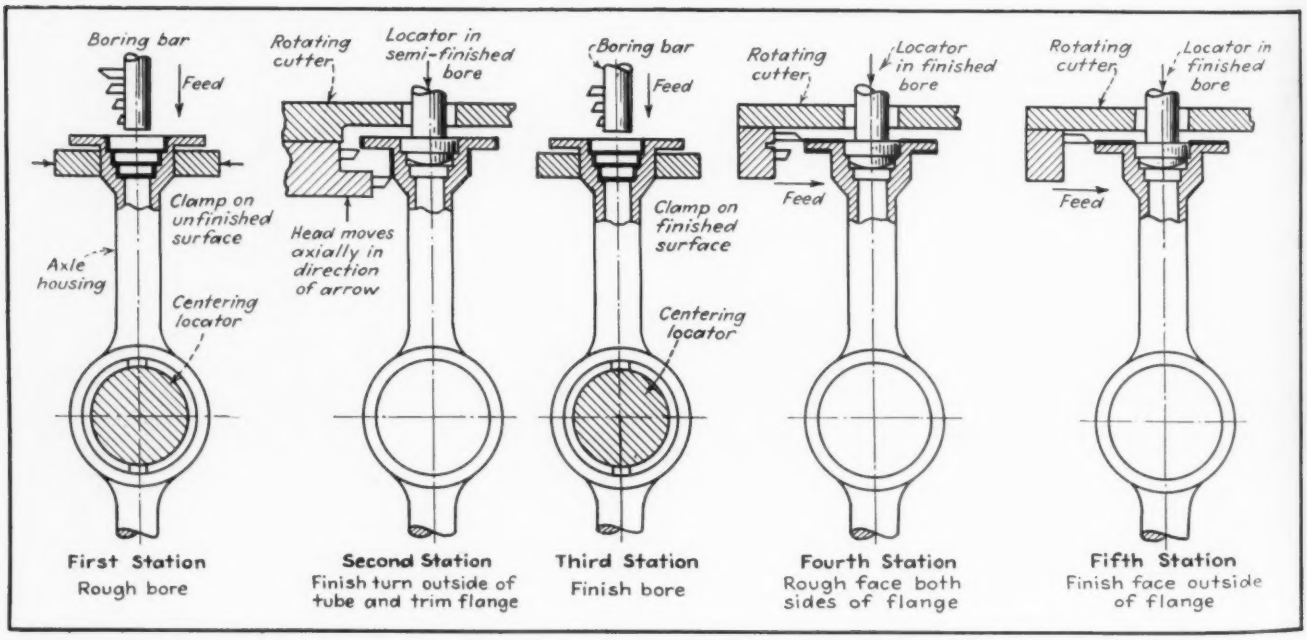
REMOTE CONTROL BLEEDER removes air from lines by operating pushbutton in cab and pumping pedal. Fluid flows from control cylinder through actuating cylinder and tank back to control cylinder. Air is forced into supply tank and escapes through two holes in bleeder filler cap.

Transfer Machine for Automotive Axle Housings

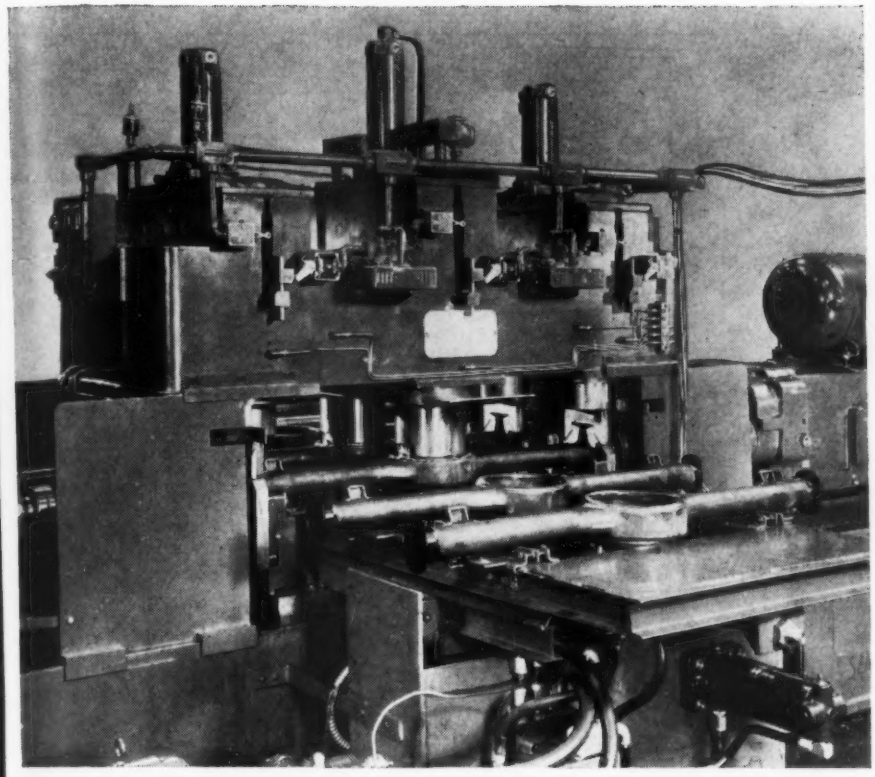
The "Transfer-matic" built by the Cross Company, Detroit, Mich. finishes both ends of automotive rear axle housings at the rate of 152 axles per hour with one operator. Emphasis is on high operating efficiency by minimizing down time and simplifying maintenance. Hydraulic valves are flange mounted to permit removal without disturbing the piping. Master control panel has indicator lights telling repairmen where to look for trouble. Separate control panels are provided for the five individual machines and a sixth for the transfer device.



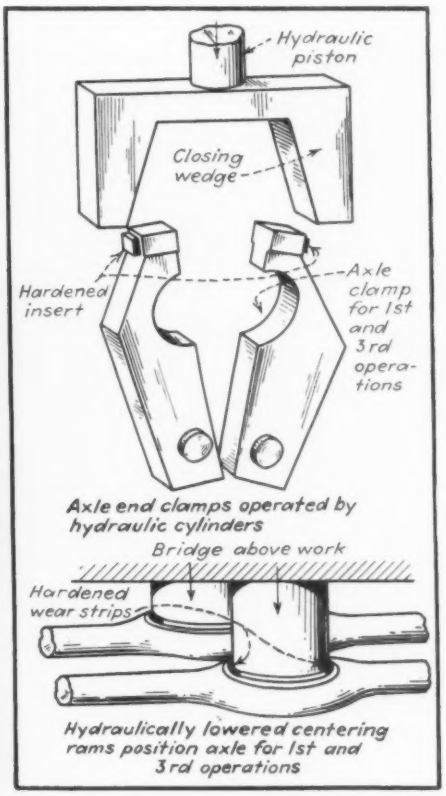
TRANSFER MACHINE has twenty axles in process simultaneously. Ten are in the individual machines, eight in idle positions and two in the loading position. A conveyor is provided to remove axles at the unload end of the machine. View is from the rear of the machine. Two housings are at unload position.



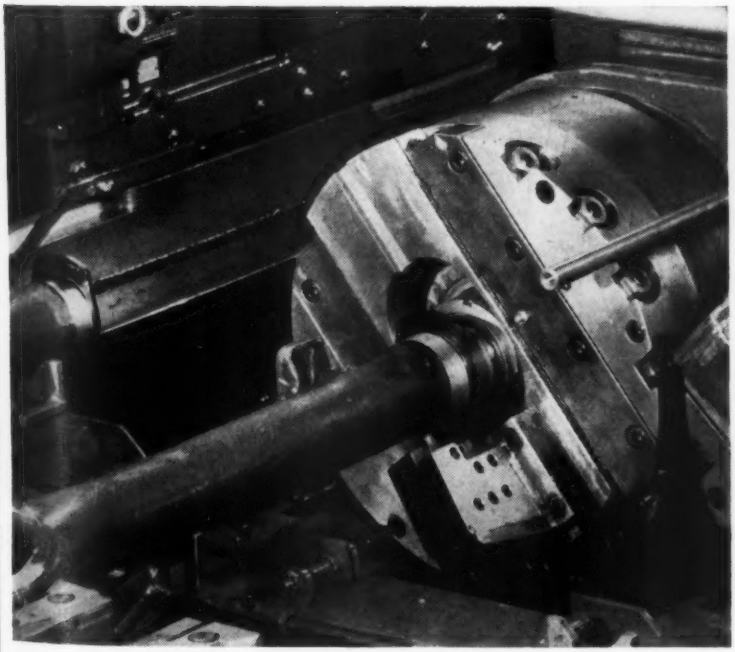
MACHINING STATION LAYOUT indicates operations performed by the machine. All five machines for these operations are independent of each other except for electronic controls. Each has its own motors, hydraulic system and method of locating the work. All machines have a centralized coolant system and have openings beneath each cutting point. Chips fall into a trench where they are carried by a conveyor to the end of the trench. There they are drained and conveyed to a disposal car. Ten thousand gallons of coolant are circulated per hour.



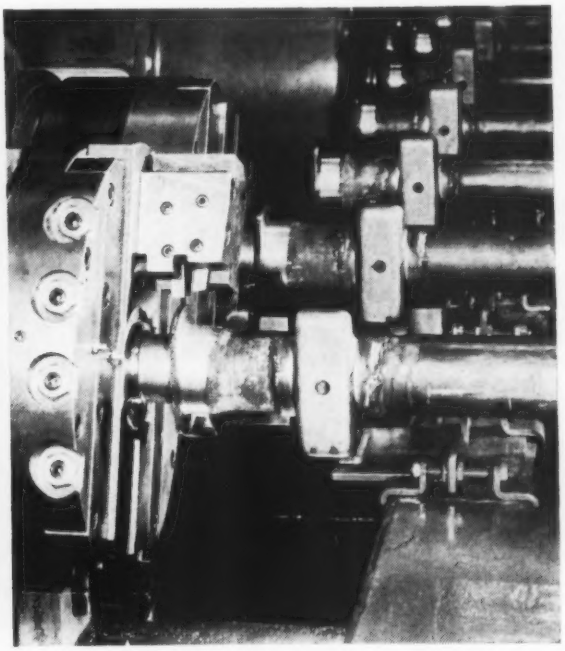
LOADING STATION VIEW shows axle in position for first operation. A pair of axles is lifted vertically and transferred horizontally from station to station. Idle station between operations is provided for inspection and service operations. Hydraulic cylinder at lower right lifts axles through rack and pinion drives. Another hydraulic cylinder is provided for horizontal transfer.


Hydraulic piston
Closing wedge
Hardened insert
Axle clamp for 1st and 3rd operations
Axle end clamps operated by hydraulic cylinders
Bridge above work
Hardened wear strips
Hydraulically lowered centering rams position axle for 1st and 3rd operations

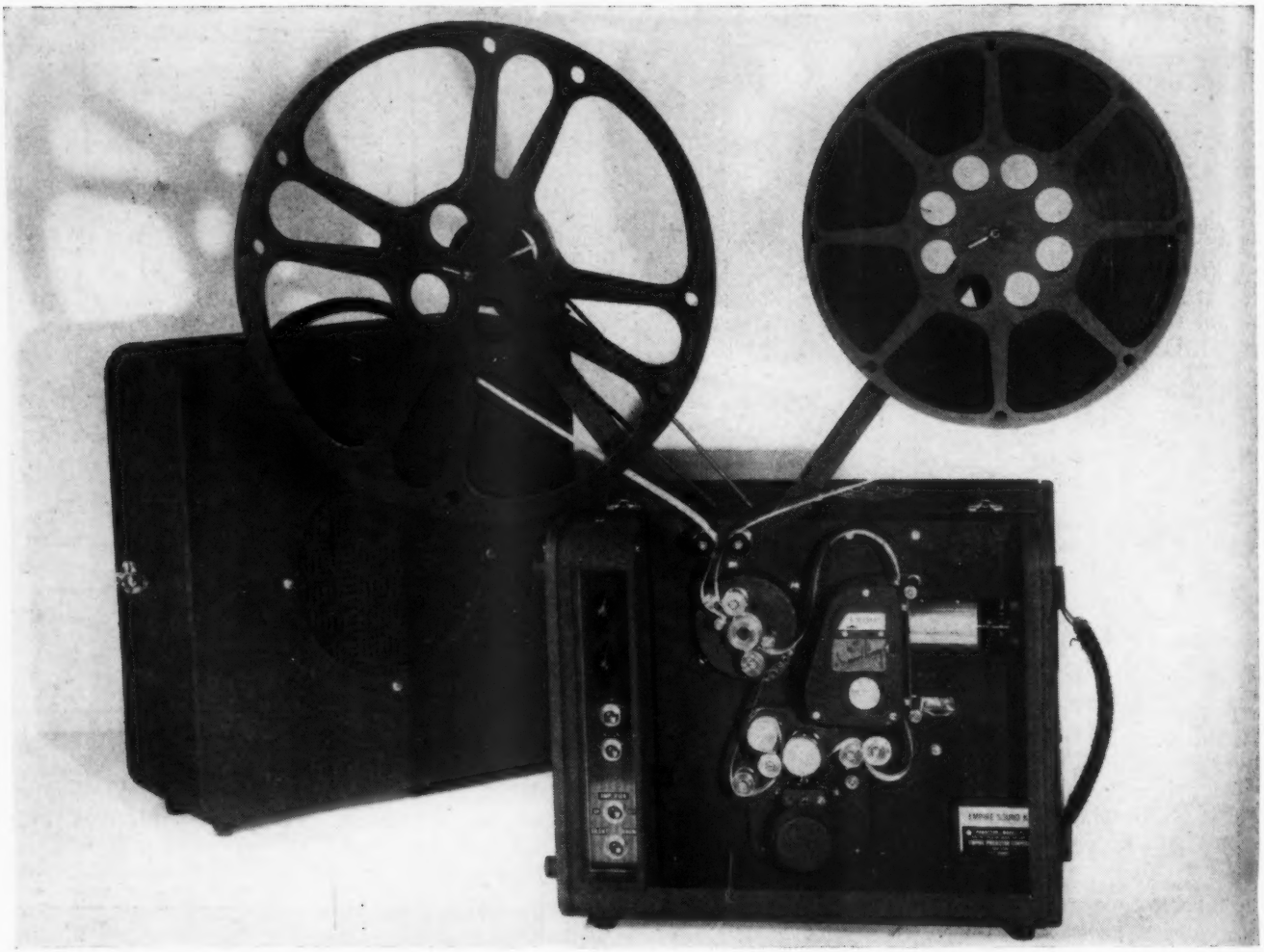
LOCATING is also done hydraulically. Details show how axles are centered by locators actuated by a vertical hydraulic cylinder mounted in upper cross rail supports.



SECOND STATION CLOSE-UP shows axle in position for outside diameter turning operation. Axle is supported by hydraulically operated locators in each end. Head rotates and moves into its housing to finish the shoulder and outside diameter of the flange. Cutter feeds crosswise into work before turning operation begins. Note V-type rough locator for tube OD of approaching axle housing.

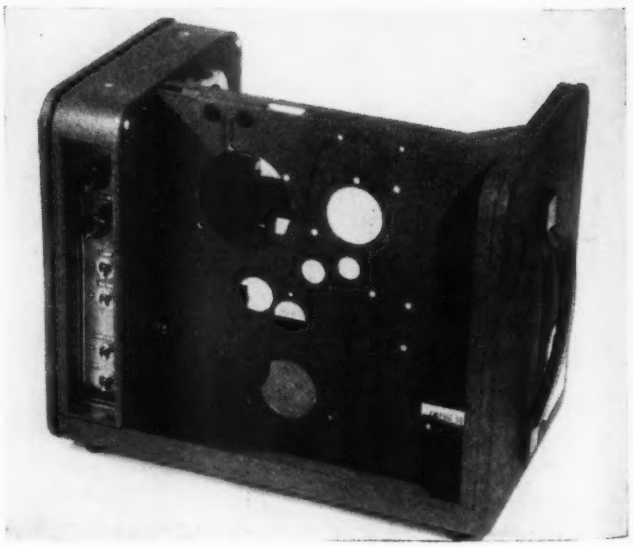


FOURTH STATION CLOSE-UP shows axle in position for straddle facing operation. Cross slide carrying the tools in the rotating head is traversed by hydraulic cylinders built into the head. Axle is supported for this operation by hydraulically operated locators that enter the end of the axle.

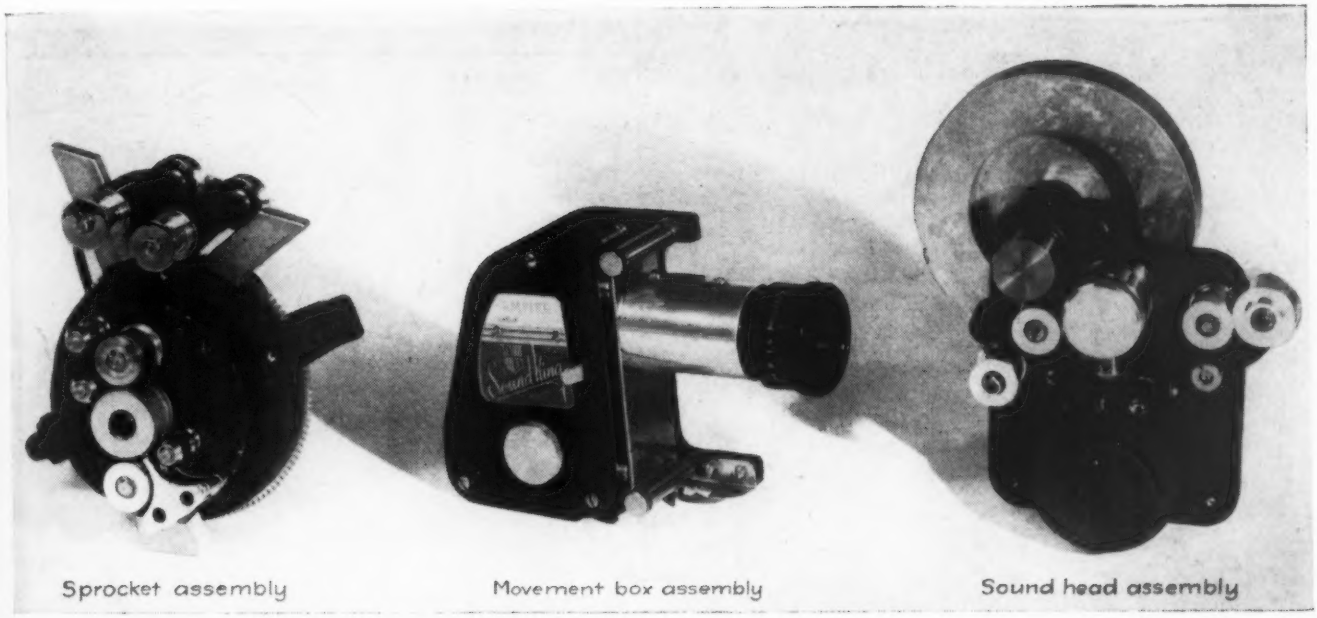


Lightweight Projector Has Sub-assembled Mechanical Units

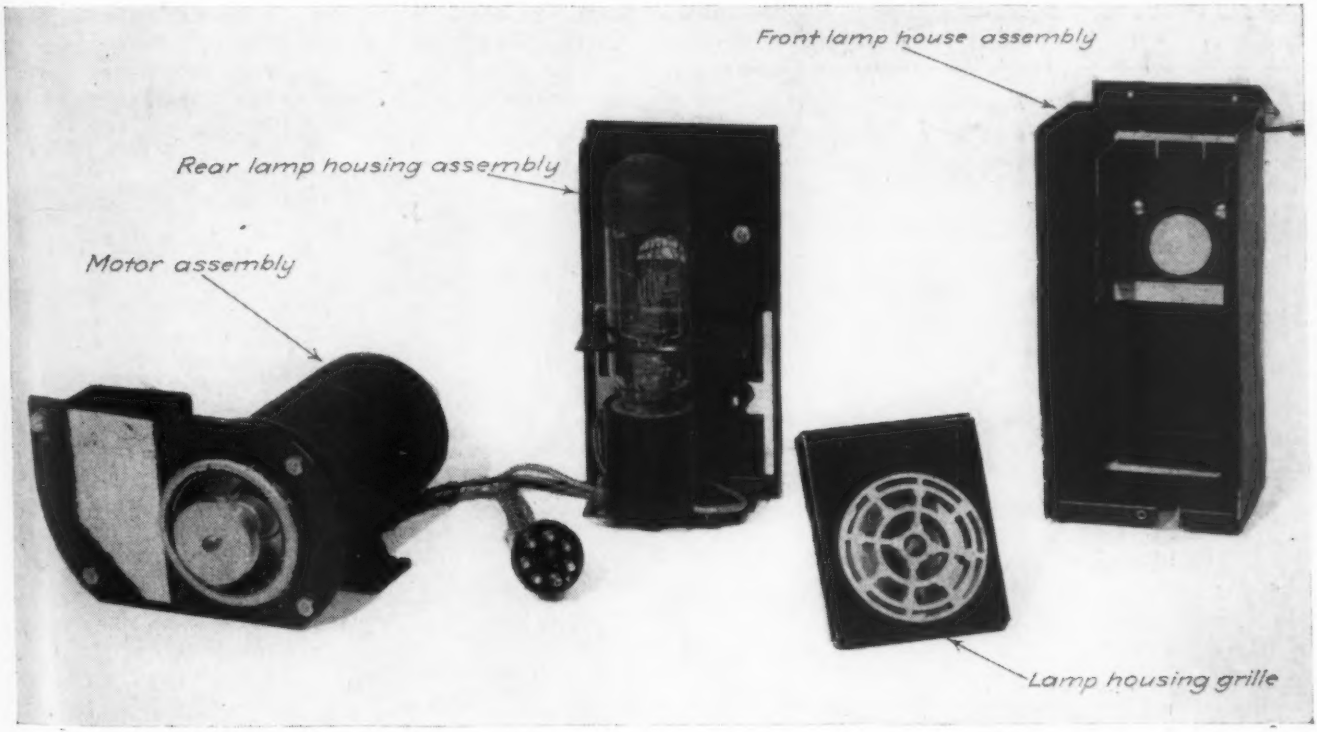
The Empire "Sound King" Model P2-16, 16 mm motion picture projector is designed for either sound or silent projection. The combined weight of projector and 8 in. speaker is 38 pounds, a weight that was achieved by using aluminum stampings and die castings in the construction. Production cost of this model was reduced by designing components as sub-assemblies. In addition to reducing cost these sub-assemblies facilitate replacement and repair operations. No lubrication is required throughout the life of the machine. Exterior finish of the two units is crackle grey enamel. Handles are provided on each unit. Projector is manufactured by the Empire Projector Corp., New York, N. Y.



FRAME is a spotwelded assembly of 52S aluminum sheet stock 0.064 in. thick. Main frame is a sandwich construction consisting of an asbestos sheet cemented between two aluminum sheets with 3M adhesive. This construction is provided for both soundproofing and heat insulation. Embossed surfaces in the frame are used as film guide indicators.

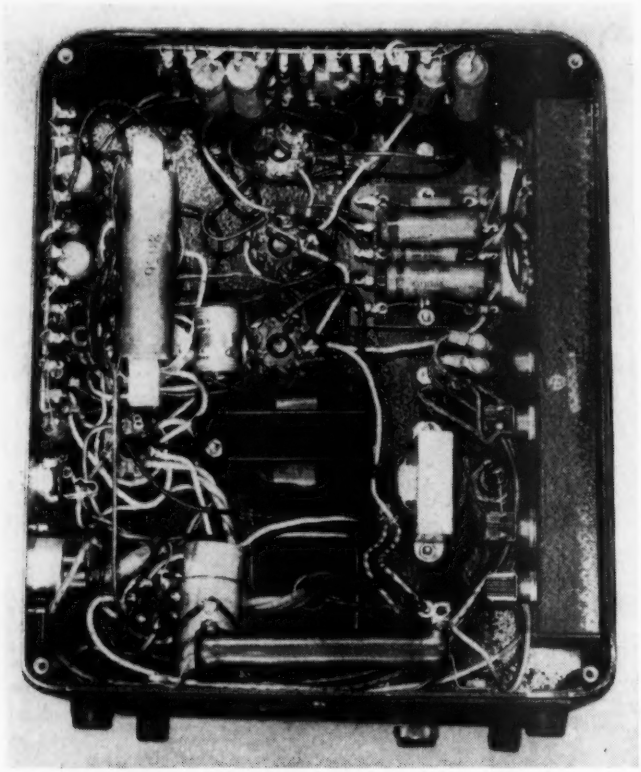


MECHANICAL SUB-ASSEMBLY UNITS include the sprocket assembly, movement box assembly and sound head assembly. Bodies of these units are aluminum die castings. Reel arm supports in the sprocket assembly are zinc alloy die castings. Large film guide rollers are duralumin with oilite bearings pressed in each end. Small guide rollers are brass, chromium plated. Included in the movement box assembly is the mounting for the 2 in. coated f1.6 lens. Flywheel in the sound head assembly is brass, cadmium plated. Flywheel shaft is supported by two sealed ball bearings. Six volt prefocussed-base exciter lamp in this assembly also serves as a threading lamp. Cartridge-type photoelectric cell used for sound reproduction is removable. Unit bodies have a crackle grey finish.

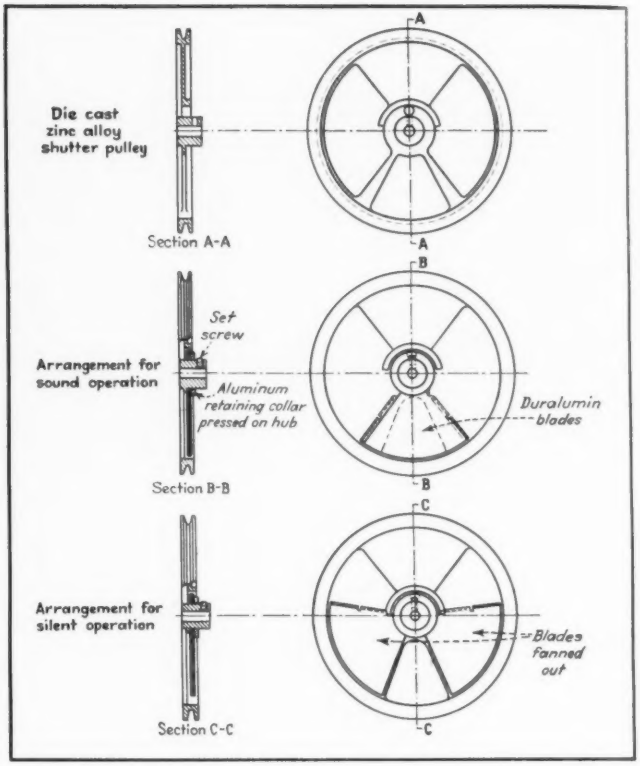


OTHER SUB-ASSEMBLIES include the motor assembly, rear lamp house assembly, lamp house grille and front lamp house assembly. Motor shaft has a two speed centrifugal governor mounted on one end and a cooling fan mounted on the other. Two motor speeds are required to provide 16 frames per second film speed for silent projection and 24 frames per second for sound projection. A wiring harness assembly provides the electrical connection between the motor and rear lamp house assemblies. Mounted in the rear lamp house is a 750 watt projection lamp. Lamp house grille mounts in top of projector, providing a means for exhausting air from the lamp house. All units have a sandwich-type construction similar to that used in the main frame, for sound proofing and heat insulation.

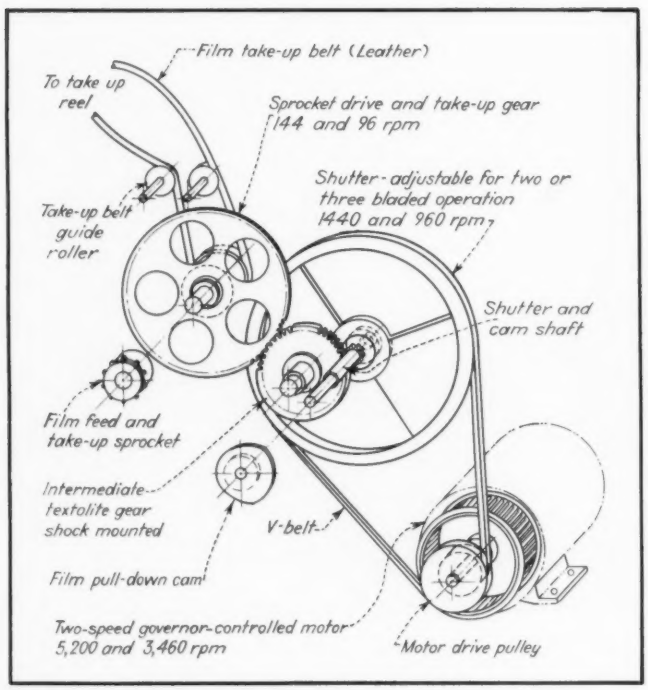
Sound Projector (continued)



AMPLIFIER UNIT, mounted on end of frame, has sub-assemblies consisting of groups of condensers and resistors arranged around the flange. Input stage is shock mounted.



ADJUSTABLE SHUTTER provides maximum light efficiency for both sound and silent projection, thus avoiding flicker. Blades are fanned out for silent projection.


Film take-up belt (Leather)
To take up reel
Sprocket drive and take-up gear 144 and 96 rpm
Shutter-adjustable for two or three bladed operation 1440 and 960 rpm
Take-up belt guide roller
Shutter and cam shaft
Film feed and take-up sprocket
Intermediate-textolite gear shock mounted
V-belt
Film pull-down cam
Two-speed governor-controlled motor 5,200 and 3,460 rpm
Motor drive pulley

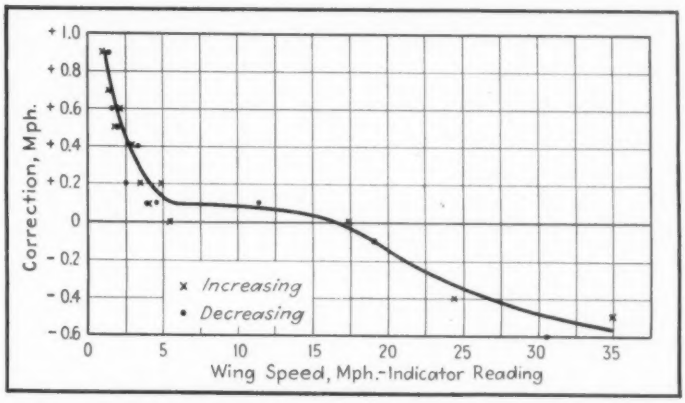
POWER DRIVE to take-up reel is through a V-belt, gear train and leather belt of circular cross-section. Steel sprocket gear and shutter pinion have generated tooth profiles. Film is driven by the sprocket mounted on the end of the take-up gear shaft. Either hand or power rewind is provided.

SPEAKER UNIT mounts in an aluminum carrying case that has clamps for holding feed and rewind arm and the take-up arm. To prevent excessive tension on the film, an adjustable friction clutch is mounted on the shaft of the take-up reel. This clutch has a felt facing cemented to one of the zinc alloy die cast drive flanges.

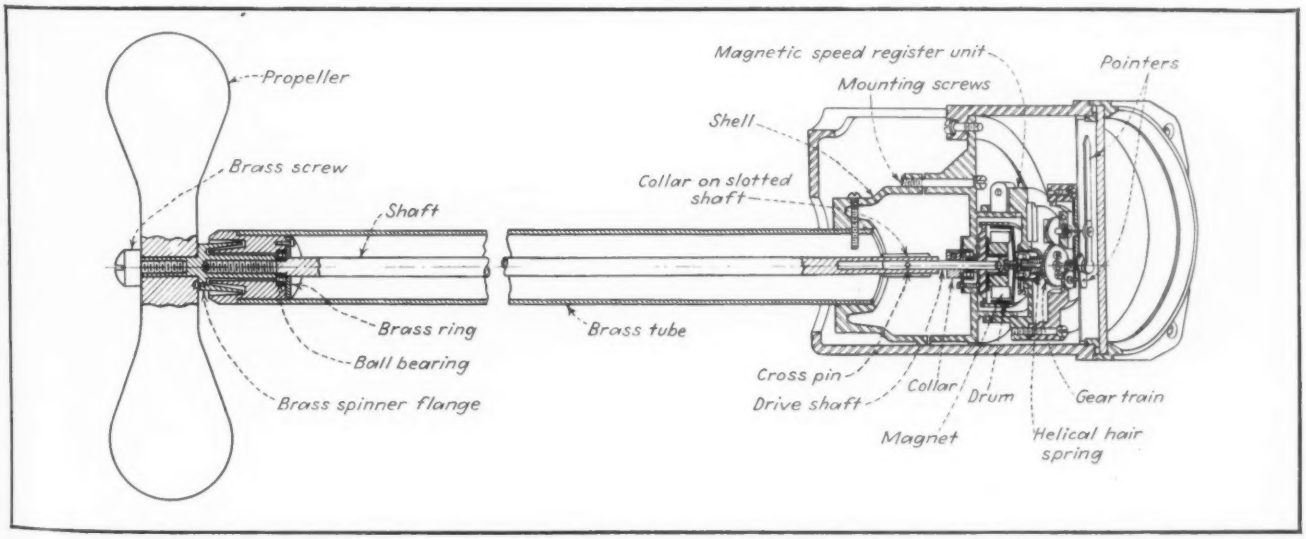
Portable Wind Speed Indicator Has Modified Tachometer Unit

PROPELLER ANEMOMETER should be held above eye level when reading approximate wind speed in any chosen direction.

Designed for use in airplane take-off tests at landing fields, this instrument measures wind speed by means of a wooden propeller connected to a magnetic tachometer indicator unit. The instrument can be held in the hands to take speed reading or it can be equipped with a vane and mounted on a base whereby it will automatically face into the wind and indicate wind direction on a pointer scale in addition to giving speed readings. Instrument has a maximum range of 35 mph on a scale graduated in tenths of a mile per hour. Minimum reading is from ½ to 1½ miles per hour. Unit was developed by S. H. J. Womack and F. Cordero of the National Bureau of Standards in cooperation with the Navy Bureau of Aeronautics, Washington, D. C.



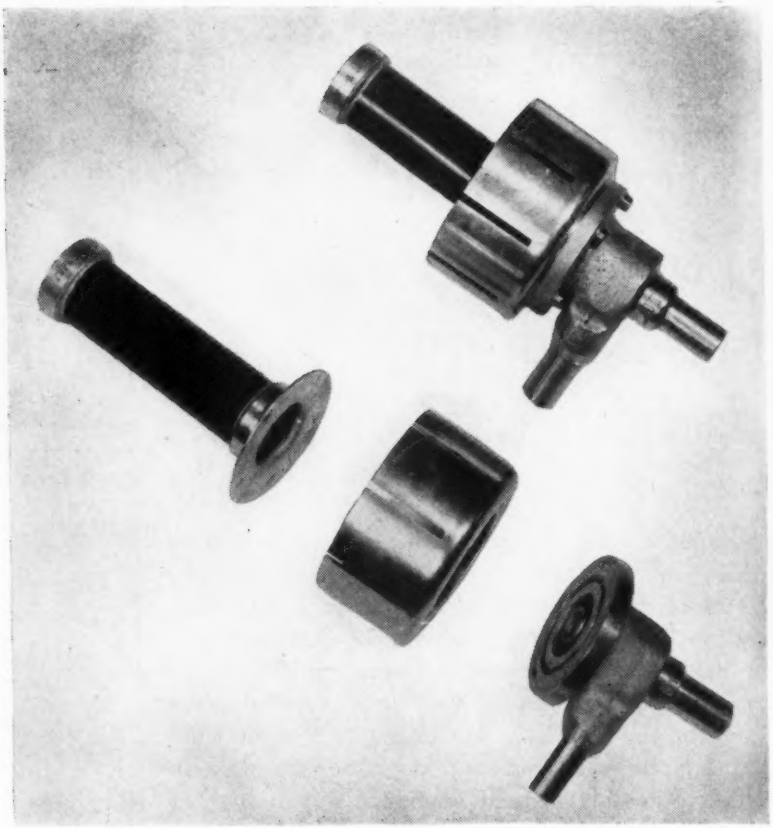
TYPICAL CORRECTION CHART for one of these instruments shows that within its 35 mph range, maximum error is from plus 0.9 mph to minus 0.6 mph. Because of friction, instrument readings begin at about 1½ mph, but will go down to ½ mph if propeller is rotating.



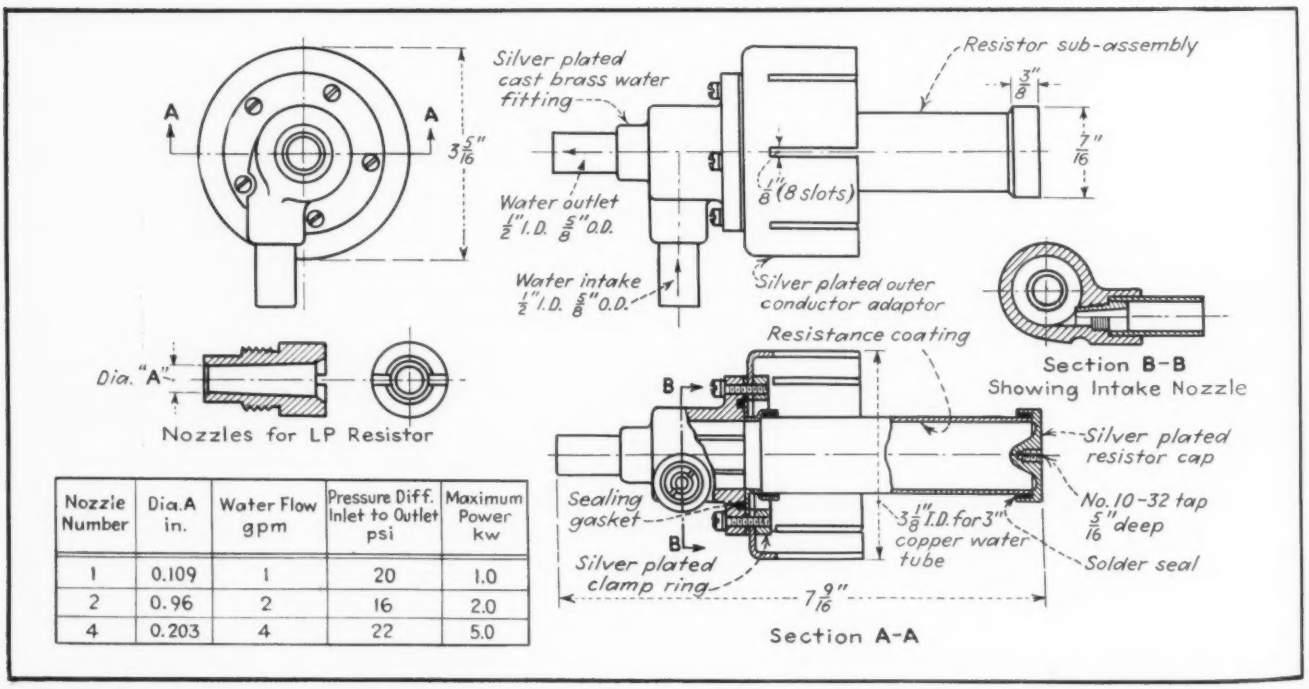
ANEMOMETER CROSS-SECTION shows how a Kollsman Navy mark "V" electric tachometer was modified to make the indicating unit. Greater sensitivity than that indicated by a pointer revolution every 10 mph can be obtained by adjusting air gap between magnet and follower cup or selecting propellers of different pitch angles. Temperature variations do not affect the accuracy of the readings in the range from minus 20C to plus 50C. Adjustment may be required at minus 50C where error is approximately 0.5 knot.

Resistor Cooled by Spiral Water Flow

High frequency, high power, type LP resistors designed for television, FM radio and dielectric heating applications, have a 0.001 in. thick composition resistance film on the interior of a Pyrex glass tube. A high velocity stream of water flows in a spiral path against the film and by centrifugal force maintains thermal contact with the entire surface. Interchangeable nozzles to suit local pressure conditions and power dissipation up to 5 kw are provided. Designed to permit mounting on the end of a coaxial line with both water intake and outlet connections at RF ground potential, they are available in sizes from 35 to 1500 ohms. Resistors are made by International Resistance Co., Philadelphia, Pa.

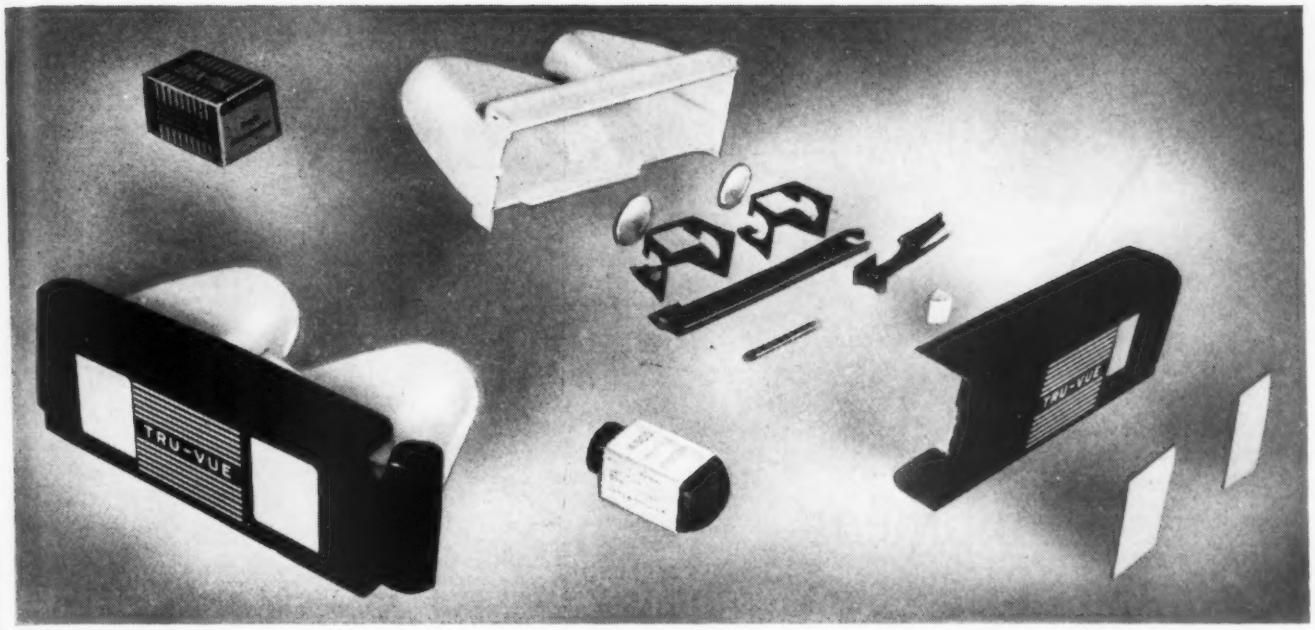


RESISTORS have an outer conductor adapter that clamps around the outside of a 3 in. coaxial line. Inner conductor is cut off 4½ in. shorter than the outer conductor and assembled to the unit by a fitting that threads into a tapped hole in the cap on the end of the resistor. Resistor will not operate on a d-c load, as electrolysis will destroy the unit.



Nozzle Number	Dia. A in.	Water Flow gpm	Pressure Diff. Inlet to Outlet psi	Maximum Power kw
1	0.109	1	20	1.0
2	0.96	2	16	2.0
4	0.203	4	22	5.0

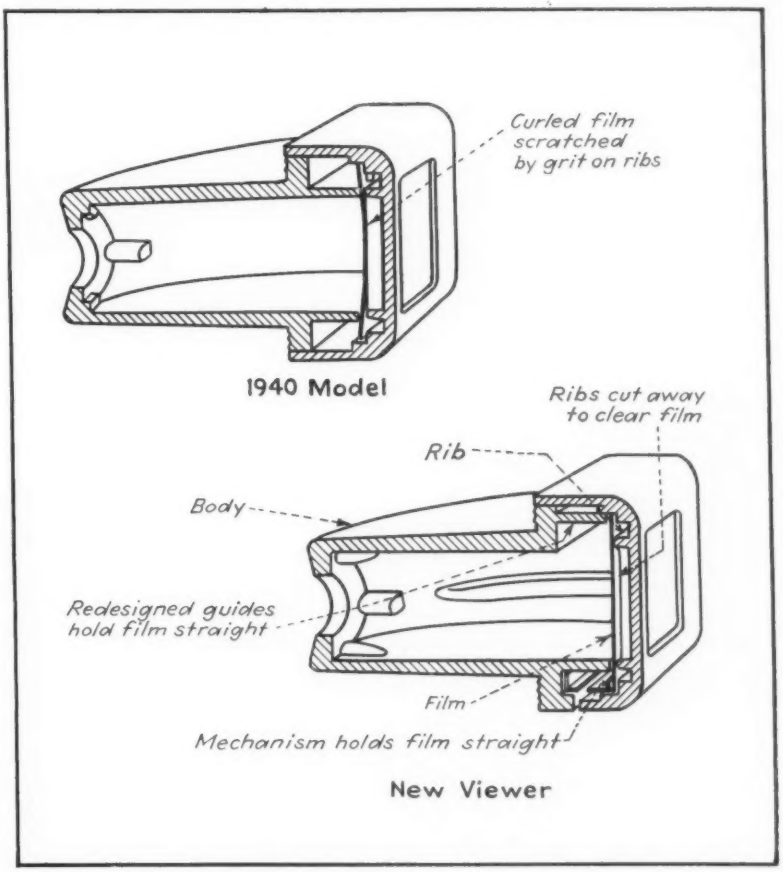
RESISTOR CROSS-SECTIONS indicate how the nozzle is placed tangentially in relation to the inside diameter of the resistor tube and thus induces spiral water flow. Resistor cap is retained on the end of the glass tube by a solder seal. All metal parts are silver plated. Table shows various nozzle sizes for given power dissipations.



NEW VIEWER has a two-tone color achieved by specifying urea plastic material instead of phenol formaldehyde.

Plastic Viewer Redesigned Without Die Cavity Change

Redesign of this plastic viewer was made without changing the die cavities. The design problem here was to give the new design an improved appearance and a more satisfactory film guide mechanism at a minimum of manufacturing cost for tool changes. The problem was solved by specifying a different plastic material and redesigning the interior of the components so that only a manufacturing change in punch design was required. Viewer is made by the Tru-Vue Co., Rock Island, Ill. The design was made in cooperation with the Mast Development Co., Davenport, Ia.

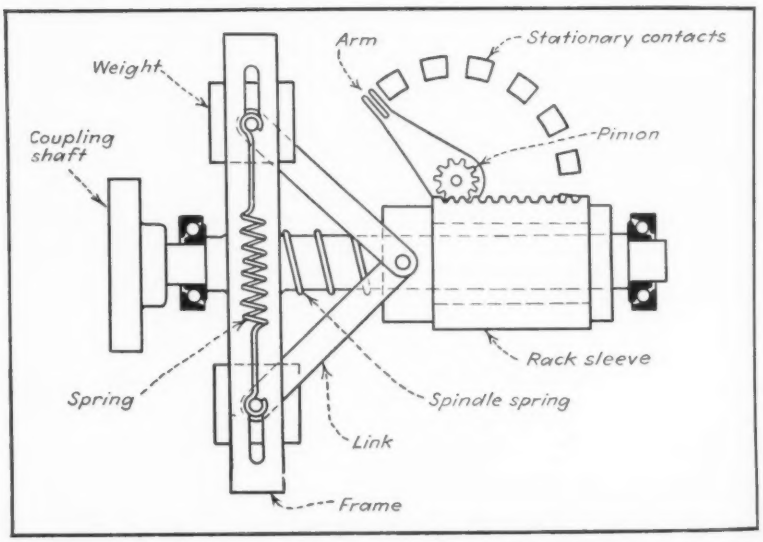


VIEWER CROSS-SECTIONS show how 1940 model was redesigned without changing die cavities. Only the punches were changed. New model supports film without touching the picture area. It can be assembled without fixtures. Only machine operation is that required to install lenses with spring clips. A metal advance claw mechanism is included in the new model, which permits film to be pulled back from the same side of the viewer from which it was inserted.

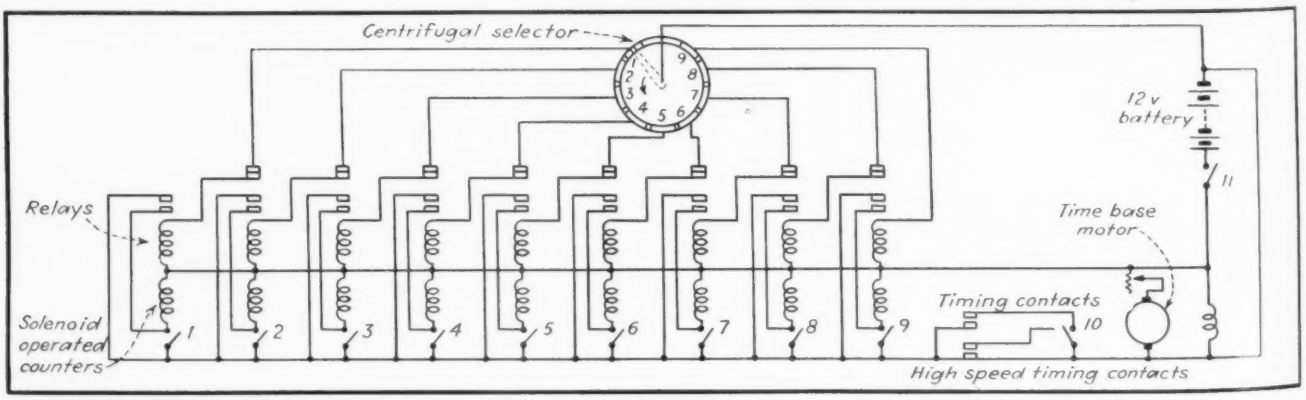
Speed-Time Analyzer Aids Engine Equipment Designer

When designing auxiliary equipment for engines, it is advantageous to know the speed that the equipment will operate throughout its working life. Because tachometer readings taken from tests are laborious and often misleading, C.A.V., Ltd. of Acton, London, England, has developed a speed-time analyzer that records and integrates with counters, the total time during which an engine runs at various speeds. A high speed engine generator developed by this company using the speed-time analyzer to determine working speed, is described on the opposite page. Generator performance curve is made from analyzer curve data.

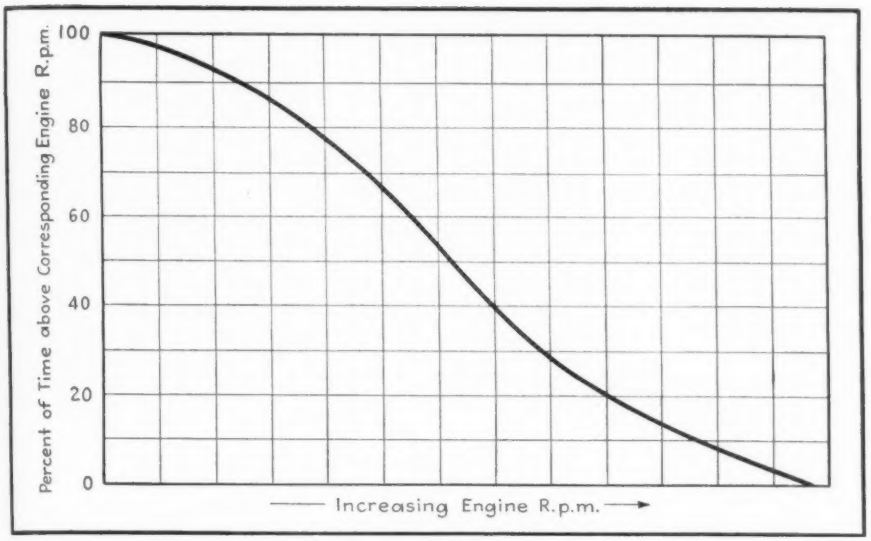
SPEED-TIME ANALYZER has a centrifugal selector switch and a recording unit that includes a time base motor and nine counters.

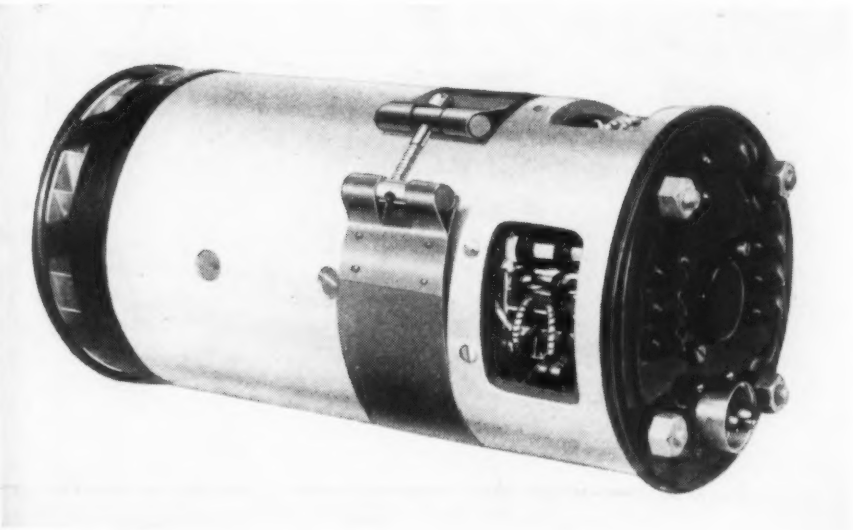


CENTRIFUGAL SWITCH has two weights that cause arm to rotate past stationary contacts. Switch is driven by engine crankshaft.



RECORDING UNIT COUNTERS are tied in electrically with the centrifugal switch and a time base motor. Timing device gives one second impulses, permitting a counter to record in seconds the running time that the engine runs within a speed range. High speed drum switch and counter switches are provided for resetting counters.





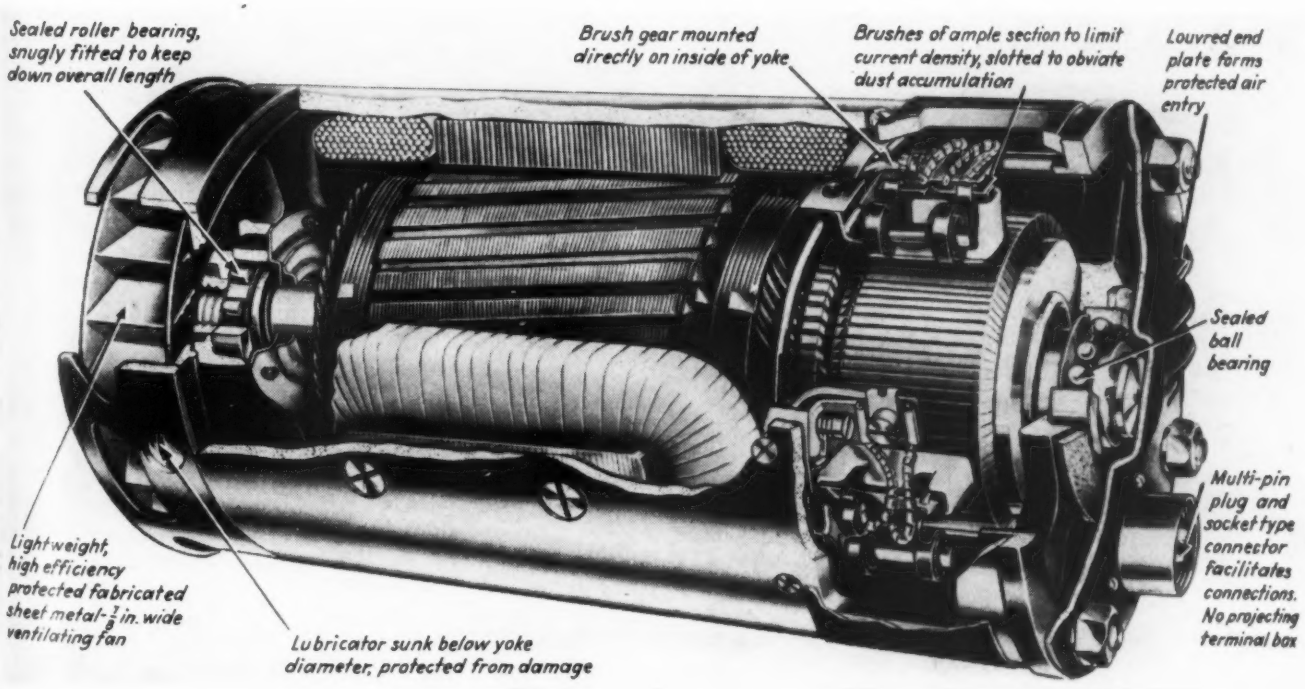
GENERATOR DESIGNED FROM ANALYZER DATA

A curve developed from readings obtained on the speed-time analyzer is shown. Usual practice with generators is to plot the percentage of the total running time above a given speed, against engine rpm.

Generator performance curve is then plotted from the known output speeds and maximum output, usually on a 100 hr basis, showing the time spent above each speed against output in amperes.

High speed generator shown was designed to fit known service conditions as determined by road tests using the analyzer. Weighing 76 lb, it is $16\frac{1}{4}$ in. long and has a 7 in. diameter. Cutting-in speed is 1150 rpm at 24 v, and maximum load speed is 1450 rpm at 55 amperes. It is driven at twice engine speed.

An extended yoke with disk-type louvered end shields that carry only bearings and connector socket is provided. Laminations and commutator are pressed on shaft. Plug and socket connector avoids using terminal box and permits generator to be located in any circumferential position in its mounting. Generator shaft is supported on the fan end by a sealed roller bearing. A sealed ball bearing supports the commutator end.


Sealed roller bearing, snugly fitted to keep down overall length
Brush gear mounted directly on inside of yoke
Brushes of ample section to limit current density, slotted to obviate dust accumulation
Louvred end plate forms protected air entry
Sealed ball bearing
Multi-pin plug and socket type connector facilitates connections. No projecting terminal box
Lightweight, high efficiency protected fabricated sheet metal-$\frac{7}{8}$ in. wide ventilating fan
Lubricator sunk below yoke diameter, protected from damage

PROGRESS IN REVIEW

In this running summary of technical developments, space restrictions do not allow giving complete details. Further information relating to any item can be obtained by writing to the Editor of Product Engineering.

PLASTICS AND RUBBER

PLASTICS are being recognized as a "here-to-stay" industry by ever-increasing numbers of engineers and managers. Surprisingly, this recognition has been belated in the profession that furthered plastics—chemical engineering. Resin production is finally given credit for being one of the basic chemical processing operations.

RECOGNITION of the basic nature of plastics is more deep-seated among physicists and engineers interested in fundamental properties of materials. This is partly a result of constant research on the part of the plastics industry itself, but can be traced also to "supplementary" value of plastics, as aids in photoelasticity studies, and as all types of models.

■ "Frozen" stresses are being studied in the Westinghouse Research Laboratories, via polarized light through photoelastic resin models. Large pieces such as a crane hook, of "Fosterite," an alkyd copolymerized with styrene, are cast by a special process for three dimensional stress studies.

■ Case-hardening has been applied with success to phenolic castings. G. A. Sterbutzel and J. T. Grey of the Cornell Aeronautical Laboratory, writing in *Modern Plastics,* report that with non-catalyzed resins surface hardness was improved to 25 percent more than the specimen cores. Compressive strength could be increased 75 percent, flexural 65 percent.

EXTRUDED PLASTICS have many design possibilities. The flexibility of the extrusion process is only now being realized, with the perfection of machining and finishing techniques.

■ Extruded plastic "lay-flat" baby bottles will soon be available. Extruded polyethylene tubing sold in continuous lengths and heat-sealed at 6 in. intervals will have sterile interiors until cut. The user cuts the tubing at one end, fills it with sterile milk, and inserts a plastic fitting with nipple over the open end. After use, this low-cost flat bottle can be discarded, eliminating washing, sterilizing and storing of bottles.

■ Extrusion of thermosetting materials, phenolics and ureas, is progressing rapidly in England. One producer alone is extruding 50 different cross sections. Thermosetting extrusion is slower and more difficult than thermoplastic. Dimensional accuracy and finish are excellent.

■ When machining to exact size is necessary, extruded tubing is superior to molded tubing because the former has more uniform density and hence machines more uniformly. Frequently the extruded tubing is post-cured in ovens at 160 C for 3½ hr, to yield a dimensionally stable product. Design of the die is the most important single factor.

ELECTRICAL APPLICATIONS of extruded plastics are more numerous than ever. In this field, polyethylene leads in new uses, because of its excellent dielectric qualities and superior moisture and corrosion resistance. Although raw materials manufacturers (Bakelite and du Pont) have proceeded with extreme caution, reports from polyethylene users abound with enthusiasm.

■ In England, polyethylene extruded tubing is braided with a resistance wire and then the entire unit covered with polyethylene, for water- and weather-resistance. The units are sold as soil-heaters.

■ Four years of research towards basically improved miniature batteries has culminated in a plastic type. Designed for small radios, hearing aids and cameras, the new batteries will be in full scale production soon.

■ Most satisfactory way of coding insulated wire for easy circuit identification is the new "Spiralon" wire, vinyl covered with spiral colored markings printed on the covering with vinyl ink. For special applications, Spiralon can also be obtained with abrasion-resistant nylon coating over the markings.

SIZE OF PLASTICS items merits continued interest. This is one of the last vestiges of growing-up stage of the plastics industry. As "functionality" becomes more important, the "mine-is-bigger-than-yours" attitude should disappear.

■ Thermoplastic tubing is now available up to 10 in. dia. Because of the close tolerances on inside and outside diameters, these tubes should find extensive use in housings, and processing equipment, in place of more expensive milled metal parts. . . . Also, flexible plastic tubing up to 3 in. dia. of clear transparent or colored material, as well as special tubing for high-pressure or high-temperature operating conditions are available. On the other end of the scale, polyethylene packaging film is now available in 0.0005 in. thickness, at a premium price.

■ Another interesting large molding, an acrylic lens, 14½ x 17½ x 3¾ in., filled with a light mineral oil of the same index of refraction, has been developed by R.C.A. to enlarge television images from 2 to 4 times. With this lens, the image received on a 7 or 10 in. television picture tube, is effectively converted to the size produced by a 15 in. tube.

PACKING AND SEALS are becoming important applications for synthetic resins. It appears that some uses have been "waiting" for new plastic materials to be developed.

■ Permanent valve packing is claimed for "Chemiseal 510," fabricated completely from unoriented Teflon (polytetrafluorethylene), a chemically inert, non-sticking, and easily deformable resinous material (see page 154, November 1947, PRODUCT ENGINEERING). The packing is inserted into valve stuffing boxes in the form of a bushing or sleeve and with low nut pressure flows to the dimensions of the box.

■ A new method of insulating magnetic coils with plastic sealing sleeves to form a tough, tight fitting insulation has been announced. The new process, which permits covering of all inner and outer surfaces in one operation, is accomplished by slipping a sealing sleeve inside the magnetic coil, turning the two ends over the outside and permitting the sleeve to air dry.

IN COMBINATION with other materials, plastics are in extensive use. Composite constructions—laminates and sandwich structures—have been publicized widely. But perhaps the use of plastics as coating has been overlooked in the "composite" field—after all, strength as well as protective qualities are required.

■ Cellulose nitrate lacquers, oil-reacted phenolics and alkyds have been used for years, but recently newer types such as melamine-alkyds were introduced. Strippable coatings have been extended to protection of tools and airplane parts.

■ Low cost of styrene resulting from the huge war development for use in GR-S synthetic rubber has aroused tremendous research effort to use this material in surface coatings. Results in general have been discouraging. However, "Ultrol," a combination of styrene and soya bean oil, is reported to be successful.

■ Other "composite" items include new crash helmets with greatly improved protection to pilots. The shell is low pressure molded of glass cloth and styrene-polyester resin, and the lining includes cellular cellulose acetate and foamed rubber, the entire unit contoured to fit the head. The helmet has molded-in movable earphones.

SPECIALIZED PROPERTIES are one of the chief selling points of plastics. To the long list, add fire resistance—combined with low density, water resistance or other desired properties.

■ A fire-resistant panel, developed initially for aircraft safety will soon also be applied to ships, hotel room doors and building partitions. "Pyroply" consists of cellular cellulose acetate sandwiched between sheets of carbon steel only 0.006 in. thick. Official tests, under C.A.A. specification, revealed that panels with an overall thickness of ¼ in. withstood temperatures of 2220 F for more than 30 min.

■ New plastic rollers with better wearing qualities than natural or synthetic rubber or leather rollers are now being produced from a modified polyvinyl alcohol resin. The new rollers are totally unaffected by fuels, oils, are lightweight, non-smearing, wear- and abrasion-resistant, have high tensile strength, and are devoid of static charge accumulation .

Synthetic rubber consumption in the United States during 1947 was well above government expectations and legal requirements. Actually the synthetic type accounted for slightly more than 50 percent of all rubber used.

NEW TYPES OF SYNTHETIC RUBBER continue to demand attention because of superior properties. As with plastics, formulations are specialized, usually in answer to specific problems. We have specialization in other fields—why not in synthetic resins and rubber?

■ The U. S. Rubber Company claims tread properties equal to or superior to natural rubber for its new synthetic rubber produced from the same chemical reactants as GR-S but reacted at lower temperature, near 0 F. instead of 125 F.

■ Another new synthetic rubber, produced from different raw materials, is Hycar P.A. (polyacrylic ester). Unvulcanized, it will find applications as an adhesive or as a coating for fabrics and paper; vulcanized forms are claimed to have outstanding resistance to heat, oil, ozone, ultra-violet light.

PRODUCT IMPROVEMENT is the order of the day in the rubber industry. The question is not natural vs synthetic, but which compound is best for a given application.

■ Big advance in early 1948 seems to be better treads for tires. In Northern states, many drivers are having worn tires recapped with a "snow-and-mud" tread, a Goodrich button-bar design, engineered to provide better pulling power with only a slight sacrifice in riding comfort. . . . Firestone is featuring its new "Polar Grip" tread with thousands of tiny suction cups claimed to grip icy pavements.

■ An oil-resistant application for nitrile-type rubber is the flexible coupling for the 4800 horsepower Pratt & Whitney engine in the new Convair-Liner commercial transport. Here oil-, gasoline- and heat-resistant requirements are satisfactorily met.

NONFERROUS METALS

SILVER, an underworked noble metal, is gradually assuming industrial stature. If governments cease to treat silver as a fine metal primarily used as a currency base and raw material for silverware, novelties and jewelry, many industrial needs could be satisfied. Cupro-nickel alloys have proved their worth as coinage, and artificial silver pricing would disappear if volume demand for industrial applications were allowed to dictate.

■ Low-cost silver brazed joints are possible.

■ Used pure as a motor brush, or mixed with carbon to form a composite, it will produce a coating on any rotating part and improve conductivity.

■ Silver can be used, according to E. L. Cady, *Scientific American*, as: Substitute for stainless steel

in food handling equipment, replacement for some tin in lead-tin solders, lining in metal cans for food and in chemical equipment.

■ Silver is almost self-healing and porous areas can be repaired by surface plating or even peening. As a bearing liner, it has good lubricity and embeddability, does not melt readily and conducts heat of friction away rapidly.

■ Powder metallurgy parts can be produced from a new chemically precipitated silver powder. Increasing use of powder metal techniques and reduced silver prices could make this powder a valuable design material.

ALL IS NOT ROSY with silver, however. B. W. Jones of the General Electric Co. recently said that silver may be inferior to other contact materials in some circuits. The two important factors in contacts are thermal capacity and oxidation—silver has low thermal capacity. Tendency to vaporize and explode when interrupting large currents may overshadow low oxidation rate. Oxidation is important when breaking moderate current a large number of times; thermal capacity important when breaking large currents. Tests bear out these generalizations.

■ Current of 20 amp at 115 v, 60 c broken by silver and tungsten contacts raises tungsten temperature higher. Arcing voltage drops are equal. This indicates that oxidation can cause additional temperature as well as erosion.

■ A three-phase bridge-type starter having ½ in. silver contacts was used to make and break 50 amp at 550 v, 60 c inductive load in air, and lost 60 mg per pole per 100,000 operations. Under same conditions, copper contacts lost 76 times as much. Copper contacts were checked in nitrogen atmosphere and lost only 100 mg—showing oxidation was major factor.

■ A 150 amp d-c contactor, with a blow-out arc interruptor, was used to make and break 430 amp at 250 volts. Arcing contacts of copper had a loss rate double that for silver. Thermal capacity properties caused rates to be more nearly equal.

PRECISION CASTING TECHNIQUES, in present practice, are receiving careful consideration by design-production teams. Three examples of different methods are worthy of note.

■ Stators on the Buick Dynaflow automatic transmission are precision cast of aluminum alloys in plaster molds. Radial vanes on stators are staggered in quadrants and vary in thickness from the outside to the root—a section that can only be made by casting.

■ By taking advantage of strength and rigidity that can be built into die-cast parts, and by using high strength aluminum alloys, a Swiss company has produced a portable sewing machine. H. K. Barton says in *Die Castings* that it is sufficiently rigid to sew thick, hard material, yet the lower arm is so small that stockings can be darned on the machine.

■ One fourth the weight and one third the size of conventional binoculars of comparable optical performance, a new model is housed in magnesium. Magnesium was chosen because it is light and has strength and rigidity necessary to maintain accuracy and durability. The housing is a complex part cast by the "lost wax" process to achieve accuracy needed for mounting the optical system.

POWDER METALLURGY may solve major metallurgical stumbling blocks facing economical production of high temperature alloys. Needed, are materials with better wear resistance that will be capable of sustained loading at 800 to 1,200 deg Centigrade. For gas turbine blades, according to H. W. Greenwood, *Metal Industry,* these properties must be in addition to resistance to corrosion and erosion.

■ Refractory metals—tantalum, tungsten or their carbides—combined with cobalt or nickel, offer best wear resistance but are difficult to fabricate; hence, the door lies open for powdered metal techniques.

■ Marked reduction in porosity, obtained by using fine particle powders, has raised powdered metal part quality to that obtained by usual metallurgical practices. . . . Close control of composition and homogeneity, as well as extension of hot-pressing methods, can produce parts with still higher quality and at lower pressures.

GAS TURBINES are responsible for much work now being done on high temperature alloys. Though most research is aimed at this one use for the metals, they will be applied in many ways, and are already introducing new techniques.

■ Superiority of nonferrous metals over steel when used at 800 C or above has been demonstrated by English alloys mentioned in *Metal Industry.* Many of these nickel or cobalt alloys contain no iron.

■ Precipitation-hardened alloys are usually used for gas turbine blades operated at 1,200 to 1,500 deg Fahrenheit. These may be bar stock or forgings of cobalt or nickel alloys, and are solution heat-treated and aged. R. H. Smith, *Iron Age,* shows that cast cobalt alloys are used above 1,500 deg Fahrenheit.

■ Gas turbine parts are made by newly patented process that combines extrusion and cold chamber die-casting techniques. Alloys of beryllium with magnesium, aluminum, copper and nickel are extruded through an orifice into a die and formed to shape by pressure. Bosses and flanges can be formed and cores are used to form undercuts.

ALUMINUM AND ITS ALLOYS continue to dominate the light metals field. Because there is so much activity surrounding aluminum, "know-how" increases in great strides.

■ Of all the possible combinations of aluminum with other elements, less than 100 are in commercial use as casting alloys. Thirty are regularly used in sand and permanent mold castings, according to F. A. Lewis, *The Foundry,* and about 10 fill most needs for high strength castings.

■ Aluminum 95-5 wire has replaced steel wire for foundry core reinforcement because it disintegrates when molten metal fills mold.

■ Aluminum has been used for making telephone booths in Canada. . . . American phone booth manufacturers are experimenting with Rigidized Metals because of their sound-absorbing properties.

■ Aluminum alloys 14S, 14ST and 24ST can be specified for parts that will be machined at surface speeds of 20,000 fpm, according to test results listed in *Iron Age*. A special turret lathe, using a single point carbide tool without cutting or cooling fluids, removed 470 cu. in. (47 lb) per minute without overloading.

■ According to H. E. Sorensen, president, Dexter Machine Products, Inc., aluminum timing gear sets are successfully replacing composition gears.

IRON AND STEEL

TESTING OF STEELS was speeded up by wartime activity in the heavy metal industry. Much has been learned concerning relationships between temperature, strength and metal composition; and testing methods. The Charpy notched-bar impact test specimen is undergoing severe criticism.

■ A. B. Bagsar recently said that conventional Charpy specimens could not show transition temperature range, in which ferritic steels shift from ductile to brittle, because small size had small restraint on deformation. He suggests using a chilled, notched plate, of full thickness, pulled apart by an eccentric tearing action instead of the usual axial loading. This method gives value in lb per sq in. for inception of brittle failure at a given temperature.

■ A recent discussion by F. Jonassen, predicated on tensile tests of plates with slots in the middle, indicated that full scale tests are of definite importance.

■ In another talk, C. W. MacGregor and N. Grossman, compared the conventional Charpy test with a slow bend test in which the strain rate was held constant. The slow bend test is believed to show the first onset of brittleness more decisively than the Charpy test, and does not require as many tests.

PLATING EFFECTS ON BASE METAL fatigue strength have been under general consideration since a question was raised in 1945. At that time, chromium plate was thought to decrease fatigue strength of nonferrous parts by 30 percent, unless highly polished prior to plating. Recent work by L. Mehr, T. T. Oberg and J. Teres on chromium plated steel adds more information.

■ Fatigue life was reduced from 8 to 50 percent by a 0.001 in. plate.

■ Least effect was produced when plate applied at 55 C in the upper end of the bright plating range. In general, lower plating current density introduced greater reduction in fatigue strength.

■ Baking to reduce hydrogen embrittlement and electrolytic polishing prior to plating were detrimental, but nitriding was beneficial.

CREEP PRINCIPLES and creep testing of high temperature parts are rapidly receiving attention as gas turbine, jet, rocket and high temperature steam investigations continue.

■ Steam turbines are expected to have a useful, efficient life of 20 years. . . . Creep tests must be carried on for thousands of hours, at low stress, to secure a reliable base for extrapolating life expectancy to this length.

■ High stress tests on jet units—life measured in hundreds or thousands of hours—must show that metals will not fail because of tearing fracture or brittle fatigue.

■ G. V. Smith, W. G. Benz and R. F. Miller have found that good metals hold load-carrying ability over a definite temperature range.

VARIOUS STEELS have been investigated by E. L. Robinson in efforts to find a pipe suitable for use in steam plants with temperatures to 1,000 deg. Fahrenheit. Creep and creep rupture data were used to compare molybdenum and chromium steels: with and without vanadium; silicon or aluminum killed; as-rolled; normalized or annealed.

■ Vanadium increases high temperature load-carrying ability.

■ Molybdenum-vanadium combination, without chromium, has not shown graphitization.

■ Silicon killing instead of aluminum, normalizing instead of annealing, coarse grain instead of fine grain are usually advantageous in any of these steels.

■ Chromium does not add much high-temperature strength, but is known to stabilize against graphitization.

■ British investigation has shown the chromium-molybdenum combination to be better than plain molybdenum, but not as good as the molbydenum-vanadium, which is much better than either.

■ W. E. Bardgett agrees that silicon killing is superior to aluminum and emphasizes the previously known, but little used, fact that phosphorous confers high-temperature load-carrying ability on plain carbon steel.

EXAMINATION OF STRESS DISTRIBUTION in a punch press frame by short-length wire strain gages, led to addition of tie rods for stiffness and better stress distribution, and to increasing the radius of a fillet. According to G. Brewer, *Testing Topics*, these changes reduced the maximum local stress by about 40 percent. One part had to be made from a higher yield strength material, but needed no design changes.

■ Use of the strain gage technique allowed a press originally designed for moderate duty service to be used on heavy duty work. Are many of our machines overdesigned?

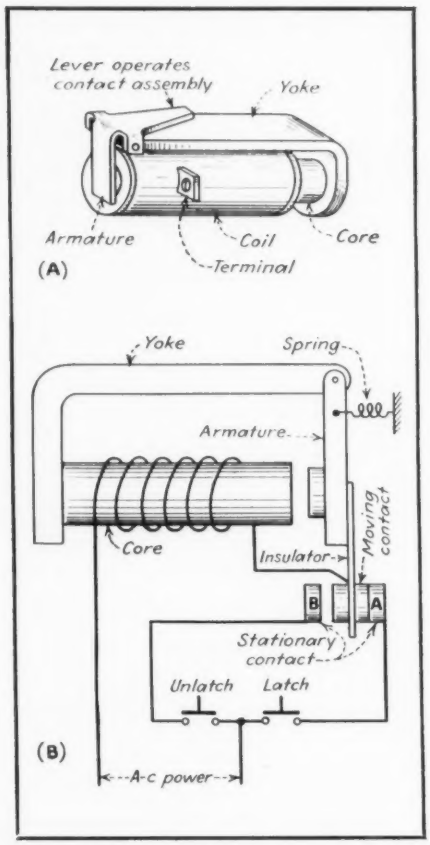


Fig. 1—(A) Typical magnetic circuit structure of an a-c or d-c relay designed for magnetic latching. (B) Schematic control circuit for operating relay on a-c.

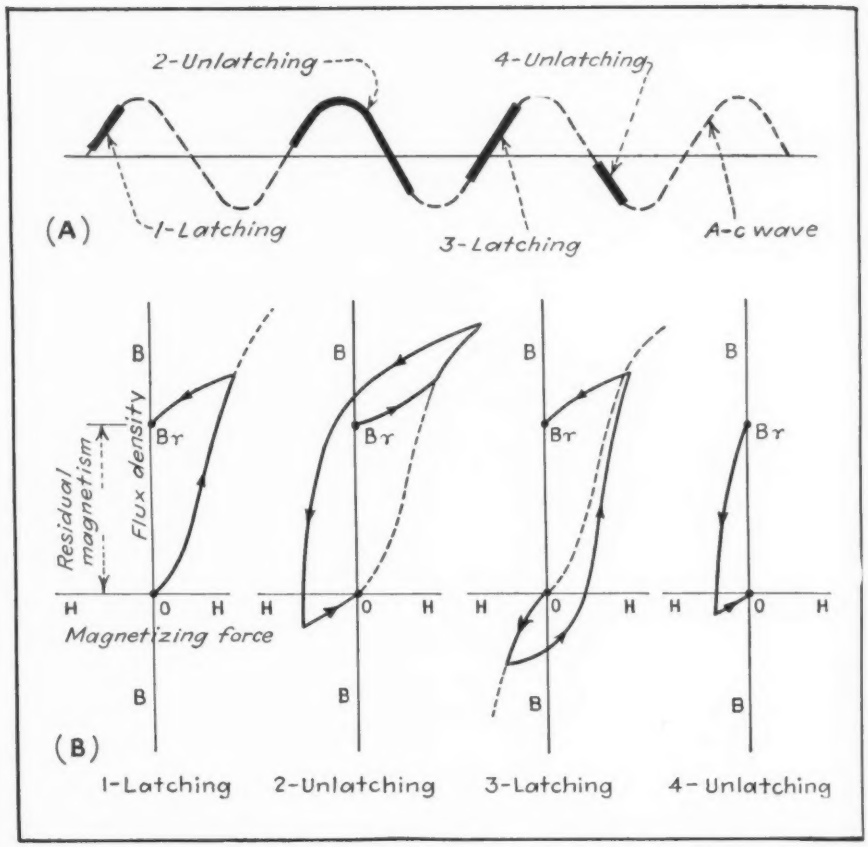


Fig. 2—(A) Heavy lines show typical impulses of current that cause the relay to latch and unlatch. (B) Basic magnetic changes 1, 2, 3, and 4 caused by respective current impulses in (A). Amount of residual in the magnetic circuit depends on position of a-c wave when coil is energized. Operating current must overcome the residual.

Magnetic Latching of Relays

Several methods for applying "memory" type relays for a-c and d-c circuits.

FRITZ DIDSZUNS
Electrical Engineer

WHEN APPLIED to control circuits of the general type that often use mechanically latched relays, a unique advantage of magnetically-latched relays is that accidental manual change of armature position does not cause permanent loss of record of last operating position. When manually released, the armature returns to its last operated position; or the last position can be determined by the state of the magnetic circuit. Advantages over ordinary types of self-holding relays with single magnetic circuit include (1) operating coils are energized only momentarily so cannot overheat and (2) magnetic latching can be used on a-c or d-c circuits with equal ease. For a-c operation, no shading coil or laminated core is required.

A magnetically-latched relay has a relatively simple magnetic structure, as shown in Fig. 1(A). The magnetic circuit is made of a material that has high retentivity, such as $3\frac{1}{2}$ percent chromium steel with a small amount of carbon. By changing and controlling the amount of residual magnetism in the core or yoke (or both) of the relay, the armature will remain open or closed. An initial electrical impulse from a pushbutton, limit switch, or other control element causes only a momentary flow of current to the relay, since the current is interrupted when the relay operates. The brief impulse of current alters the magnetization of the core. High magnetization attracts and holds the spring-biased armature. At low magnetization, the force of the spring overpowers the magnetic pull and opens the armature. Fundamentally, the same magnetic circuit will operate on either a-c or d-c supply.

A typical control circuit for operating the magnetically latched relay on alternating current is shown in Fig. 1(B). Only a single coil is needed since the a-c wave goes through zero every cycle. In Fig. 1(B), closing the latch pushbutton completes the circuit through the coil. The armature closes, thus (1) opening contact *A*, (2) interrupting the circuit, and (3) transferring the control circuit to contact *B*. The armature remains held in the closed position by residual magnetism. Depressing the unlatch pushbutton energizes the coil. As the cyclic current reverses the residual magnetism is decreased and the spring opens the armature, thus in interrupting the circuit at *B* and closing contact *A*. For simplicity, only the auxiliary contacts that control the momentary impulse of current are shown. In service the armature also carries power contacts.

A range of conditions of current flows in the coil for latching and un-

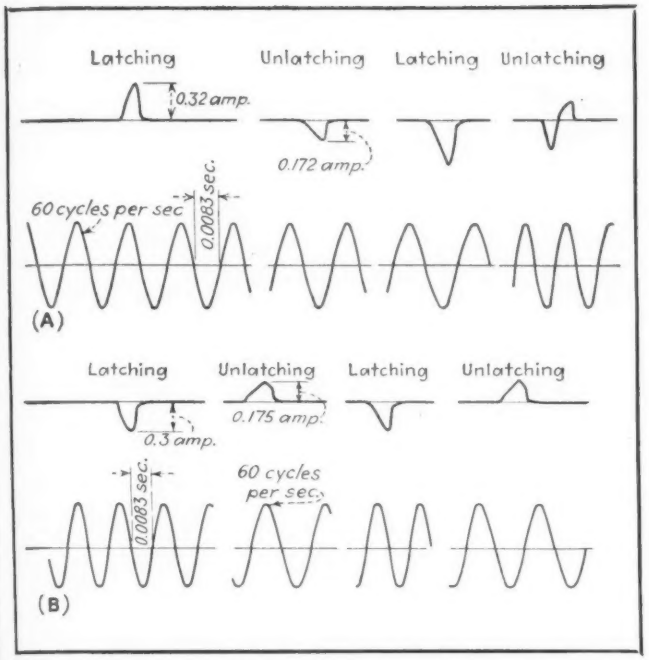


Fig. 3—Current for relay with 175 ohm coil, operating on 120 volts. No series resistance for latching; 300 ohms resistance for unlatching. (A) Alternating current, 60 cycle (B) Direct current.

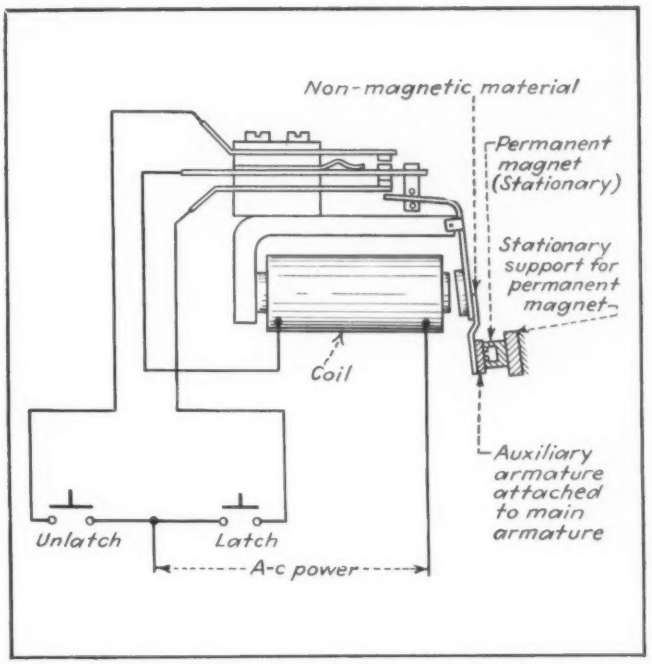


Fig. 4—Holding force is increased by permanent magnet retarding armature until magnetizing current reaches predetermined value. For special circuits this is a useful characteristic.

Table I—Characteristics of a Magnetically Latched Relay Operating on A-C

Power	A-c 120 volt, 60 cycles
Coil	5,000 turns, 175 ohms
Operating current, amp	Varies with (1) forces resisting latching of armature and (2) magnitude of a-c current wave when relay is energized. See oscillograms.
Duration of operating impulse, sec	0.004 to 0.012
Pull to operate auxiliary and power contacts, oz	16
Total force holding contacts closed, oz.	22 to 48
General	Armature will unlatch without series resistance in coil: but 300 ohm in release circuit increased "memory" by reducing the residual.

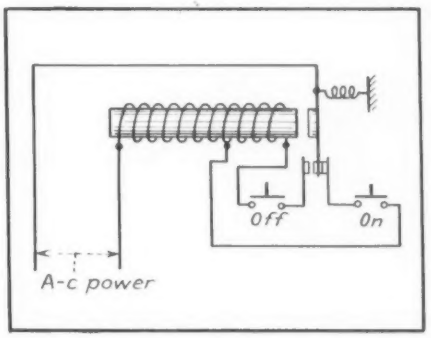


Fig. 5—Tapped coil on a-c relay provides positive operation on some applications.

latching is shown in Fig. 2(A). The effect of the current impulses on magnetization is shown in Fig. 2(B). Intermedite operating positions result in different magnitudes of residual induction *B*. Any slight residual induction in the unlatched position is caused by the forces that try to return the armature to the unlatched or open position.

The operating current depends on the position of the a-c wave when the coil is energized and the forces acting against latching the armature. A typical range of operating current for a-c- and d-c- shown in Fig. 3 by oscillograms.

Other general operating characteristics of a magnetically latched relay operating on a-c are given in Table I. For comparison, when the same relay was operated on d-c: Forces to operate and hold the contacts were comparable; approximate duration of impulse, 0.007 sec; and 300 ohms in series with the coil was necessary to obtain proper release.

Tests show that the total holding forces vary depending upon the magnitude of the magnetizing current. The minimum holding force of a typical relay was 6 oz more than the force required to operate the contacts. If the pull required to operate the contacts was 20 oz, for example, then the minimum total holding force was 26 oz. But the maximum force remained 48 oz. This minimum difference of 6 oz over the pull required to operate the contacts is obtained by using a comparatively large airgap. This allows the magnetizing current to increase to a larger value before the current is interrupted when the relay operates on a part of the cycle that results in low current values.

The maximum force of 48 oz is obtained when the relay is energized at a time during the cycle that produces peak values. These are higher than those obtainable at 120 volts d-c. Therefore, 32 oz maximum on d-c was obtained as compared with 48 oz on a-c operation.

The final holding force of a relay can be increased by holding the armature back until the magnetizing current reaches a certain magnitude. One such method, shown in Fig. 4, uses a permanent magnet.

For proper operation on a-c, relays should pick up on an impulse lasting less than one half cycle. When needed, series resistance can be inserted in the release circuit if the impedance does not increase enough when the armature is attracted. Another method is to use a tapped coil, as shown in Fig. 5, for positive operation.

For direct current, two coils wound in opposite directions on a common core can also be used. One coil magnetizes the core and the second coil

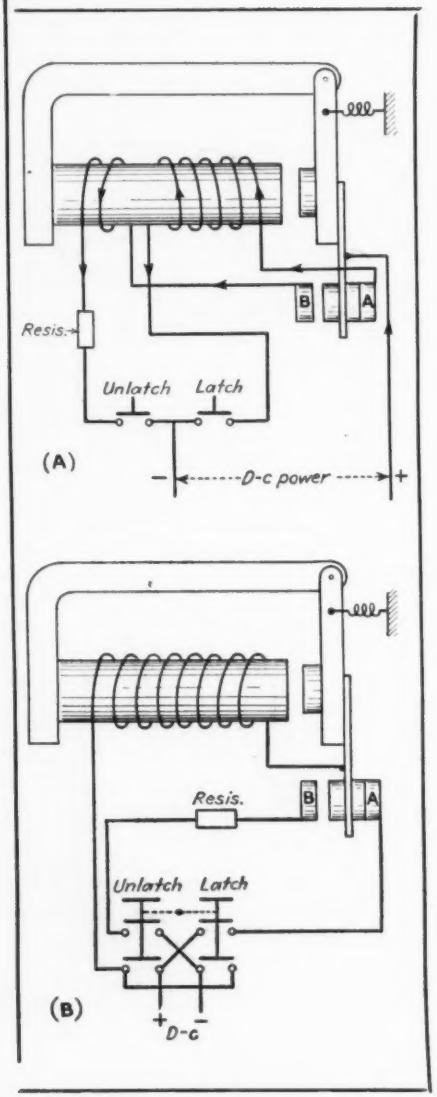


Fig. 6—Schematic of typical d-c control circuits for: (A) Two coil-type relay and (B) single coil type of latching relay.

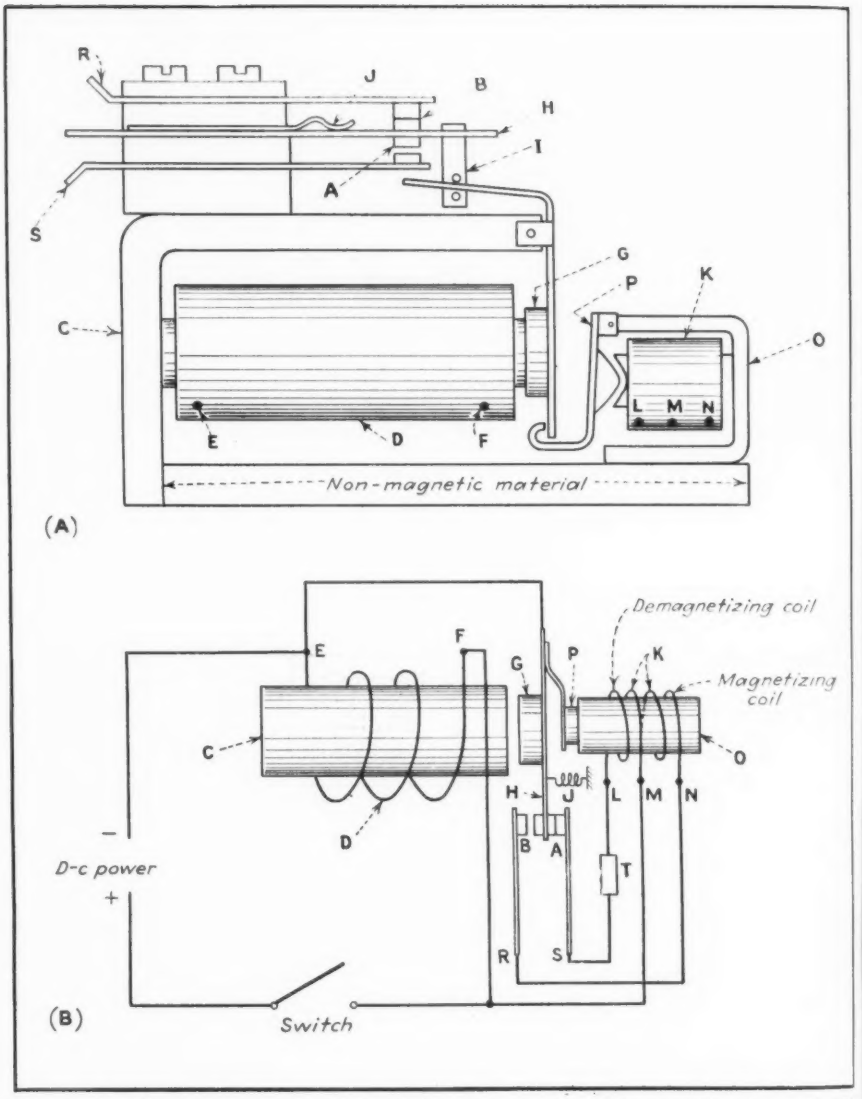


Fig. 7—Combination magnetically latched contactor: (A) Diagramatic view and (B) schematic control circuit. The auxiliary magnet of high retentivity steel speeds return of the relay armature; and also it prevents false operation from vibration.

produces reverse ampere turns that create a neutralizing flux. Another type uses a single coil and a reversing switch. In Fig. 6 (A) depressing the latch pushbutton attracts the armature, which is held in position by residual magnetism after the circuit is interrupted. Energizing the second coil bucks out the residual flux and the spring opens the contact. The series resistor in the unlatching circuit limits the current to value that practically demagnetizes the core, but does not reverse the residual. This increases the pick-up speed when latching. Fig. 6 (B) shows how a pushbutton reverses the direction of current flowing through a single coil d-c relay.

Another scheme for magnetic latching comprises a combination relay and auxiliary magnet as shown in Fig. 7. The yoke and core of the relay is ordinary silicon steel, but that of the magnet uses high retentivity steel. The auxiliary magnet speeds the return movement of the relay armature and also prevents contact points from making or breaking circuits accidentally when the relay is not in operation, such as from vibration. The contact points shown are only those required for the operation of the relay and the auxiliary magnet.

In Fig. 7 (B), closing of the switch completes two circuits: (1) From plus-switch-*F*-*D*-*E*-minus: also the parallel circuit, (2) from plus-switch-*M*-*K*-*L*-*T*-*S*-*A*-*H*-*E*-minus. This energizes the relay and also demagnetizes core *O*, so that the armature *G* is attracted to core *C*, taking with it the armature *P*, of the auxiliary magnet. Contact *A* is opened and *B* closed when the armature *G* is very close to relay core *C*. Closing contact *B* completes the following circuit: plus-switch-*M*-*K*-*N*-*R*-*B*-*H*-*E*-minus. This magnetizes core *Q* and armature *P* pulls armature *G*. But because of the momentum of armature *G* when moving toward core *C*, and also because of the time it takes for the current in coil *K* to build up, armature *G* is in the final position before the core *O* is fully magnetized.

The relay has a small airgap so that the pull of core *C* on armature *G* is sufficient to keep its contact closed regardless of the pull between *P* and *O* tending to open contact *B*. As soon as the switch is opened, the action of this pull causes the return of the armature, in parallel with the action of spring *J*, thus speeding return of armature and contacts. Because of the residual magnetism in *O*, the armature *G* stays locked in the rest position without any line connection and does not depend on spring tension. Thus if designed for this purpose, the locking property would prevent the closing of contacts even if the return spring is weakened or broken.

HOW TO ORGANIZE FOR

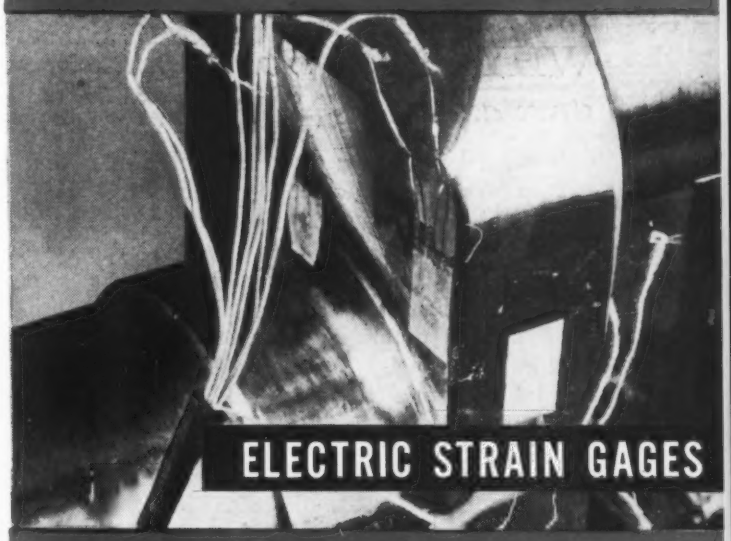
Experimental Stress Analysis

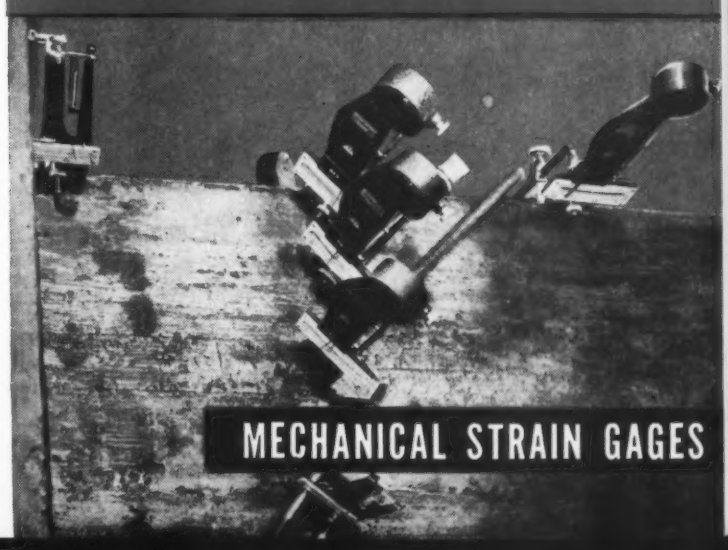
Techniques

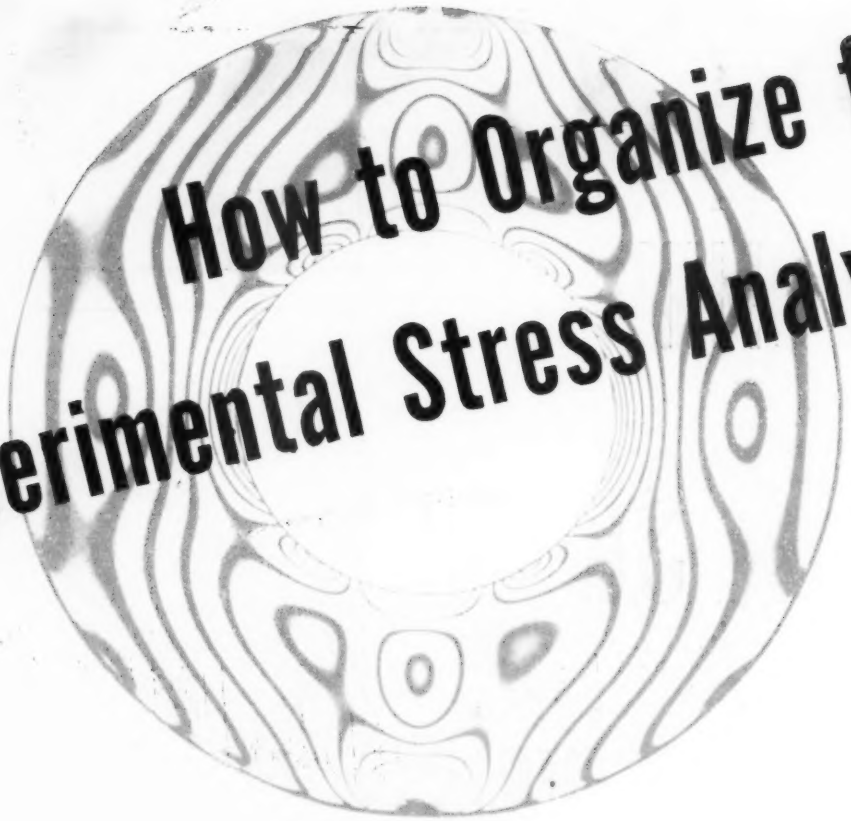
Advantages and Limitations

Cost of Equipment • Applications

Results and Savings







How to Organize for Experimental Stress Analysis

WHY *consider experimental stress analysis?*

Intelligent use of the tools of experimental stress analysis enables the research and development engineer to complete design investigations rapidly and to obtain otherwise obscure engineering data. Stresses, deflections and strains in any structure or member can be determined to an amazing degree of accuracy. Frequently conditions revealed are far different from the expected, and desirable product improvements can be made. Often the designer can, relatively quickly:

1. Achieve optimum distribution of material.
2. Increase load carrying capacity and service life of the structural members.
3. Minimize peak and local stresses.
4. Reduce the weight of the structure.
5. Decrease fabrication, material and other production costs.
6. Complete a sound structural design, saving time and development expense.

WHEN *to consider experimental stress analysis.*

There are three general instances when experimental methods are indicated for design analysis:

1. When the problem is too complicated for accurate mathematical solution. (And most problems are, some stress analysts say. Others hold that an experimental investigation usually should be combined with a detailed mathematical analysis. Even though this solution may not be entirely correct theoretically, it will provide a rational guide.)

   Examples:
   - (a) When stresses are indeterminant because of dynamic loads.
   - (b) When deformations may shift the load in an unpredictable and dangerous fashion.
   - (c) When serious residual and internal stresses are created by production or assembly processes.
2. When the mathematical solution or service tests take too much time.

   Examples:
   - (a) When the engineer is faced with a large investment in calculation time or lengthy tests of components.
   - (b) To check operating stresses so as to determine the maximum safe service speed for machine elements, particularly on older machines which may have been overdesigned.
   - (d) Experimental analysis on models, rather than full-scale units, thus shortening development time and reducing construction costs.
3. When the correctness of the design solution must be determined.

   Examples:
   - (a) A check on product performance after a change

in shape, material, heat-treatment, or joining of important structural members.

(b) Verification of a theory or empirical relationships.

(c) To settle an engineering argument so that the design decision may be based on fact, rather than prejudice.

(d) To study failures on the spot, so that structural inadequacies can be remedied without a time-consuming major redesign.

HOW *experimental stress data are obtained.*

The four most frequently used techniques are:

BRITTLE COATING—to get the overall picture of surface stresses and to locate regions of dangerous stress concentrations.

PHOTOELASTICITY—to study stress distribution through a cross section. Effective for determining the stress concentration factors, a primary cause of failure. Also useful in the study of the stress gradient, which in turn is related to notch sensitivity.

MECHANICAL STRAIN GAGES OR EXTENSOMETERS—to measure directly deformation on a portion of the surface. Many limitations prevent universal application. Some special mechanical gages can make measurements beyond the capabilities of other techniques.

ELECTRIC STRAIN GAGES—most versatile of the stress analyst's tools; highly accurate and sensitive. Because they are minute, continuously indicating, and their responses can be recorded, many ingenious applications are possible.

Specifically, the various techniques enable the engineer to:

1. Measure the strain at almost any point on a surface.
2. Compute the kind, direction and amount of the corresponding stresses. Determine directly static stresses below the surface (photoelastic methods).
3. Obtain accurate information on the load.
4. Study deflections and stresses under shock and impact loads.
5. Obtain graphs of stresses and strains developed during a cycle of operation.
6. Measure residual stresses created during fabrication, assembly, and use.
7. Study changes in stress distribution as load is increased or fatigue develops.
8. Visualize, so as to avoid, stress-raising design features that ultimately cause failure.

WHAT *does experimental stress equipment cost?*

As will be shown, costs vary with the method used, the information required, and the speed and accuracy desired. Frequently the expense is insignificant, even less than would be the cost of calculating the data. Sometimes the equipment needed can be assembled for less than $100. On the other hand, for a dynamic loading study on a complex structure such as an airplane wing, $100,000 might be spent for instrumentation. For many machine design studies, a $1,500 investment will provide equipment that is adequate to make valuable design improvements. Furthermore, most of this equipment is permanent and can be used for future investigations.

The experience of many companies who embarked on a modest program has been that the results impelled them to expand the initial effort greatly and profitably.

WHO *can run an experimental stress analysis program?*

One man with knowledge of the fundamental behavior of materials and the theory of elasticity can handle the average program. This individual needs a mathematical background, plus patience, tenacity and intuition. Careful organization and good planning are requisites for success. Above all the engineer should decide what he wants to know before starting any test.

It should not be construed that this experimental work is easy; however, many practical product improvements can be made by the competent experimental stress analyst.

WHERE *can one learn more about experimental stress analysis?*

References on specific techniques are included later in their appropriate sections. For a general background, refer to:

"Handbook of Experimental Stress Analysis," sponsored by The Society for Experimental Stress Analysis to be published Spring, 1948, by John Wiley & Sons. This is the basic instruction manual.

Proceedings of the Society for Experimental Stress Analysis, annually from 1941 to date. These describe applications of various techniques to dozens of diverse studies ranging from propeller hub vibrations to the impact resistance of the human skull.

"Types of Strain Measuring Devices and Their Range of Utility" by Karl F. Smith, PRODUCT ENGINEERING, Jan. 1947, 107-110. Describes briefly a number of strain gaging methods and gives numerous references.

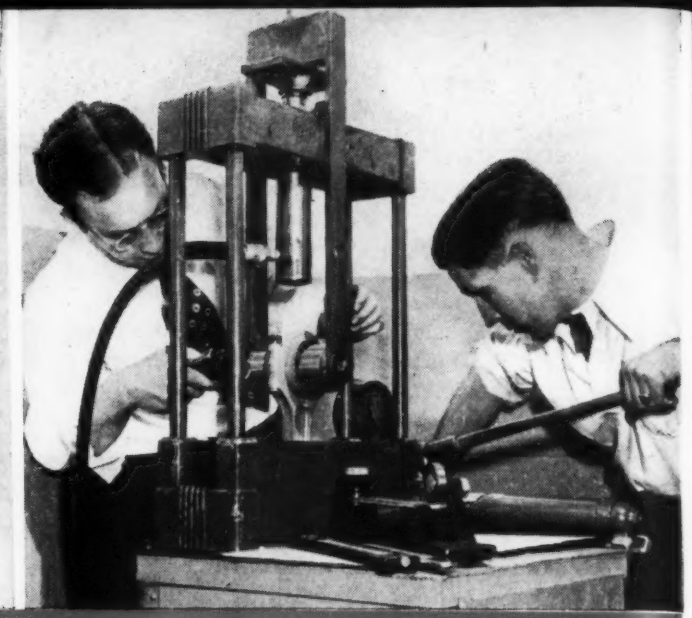
"Mechanical Measurements by Electrical Methods" by Howard C. Roberts, The Instruments Publishing Co., Inc., Pittsburgh, Pa., 1946.

"Methods of Stress Determination in Engine Parts" by Charles Lipson, *SAE Journal of Transactions,* Vol 51, No. 4, 105-124. An outstanding article showing how each technique has a place in solving engine design problems.

"Symposium on Experimental Stress Analysis" in PRODUCT ENGINEERING, Jan. 1947. Describes a number of design improvements that were made through the use of the different experimental techniques.

Following sections discuss the various equipment requirements, advantages, limitations, costs, and include specific references, for each technique.

Stresscoat Unit for Brittle Coating Analysis



Applying Load With a Hydraulic Press

Brittle Coating

PRINCIPLE

To cover the structure with a coating that will crack wherever strain exceeds a fixed amount.

METHOD

The part is degreased, then sprayed with an aluminum pigmented undercoating. Fifteen minutes later a strain indicating coating, "Stresscoat*," is sprayed on the object. At this time several calibration strips are similarly coated. After drying 5 to 20 hr the object is ready for test.

Generally the part is loaded while the operator simultaneously observes the formation of cracks in the coating as the surface of the specimen strains beyond the ultimate strength of the coating. These cracks form at right angles to the direction of the principal tensile strain. Knowing the modulus of elasticity for the material and the amount of strain that will crack the coating, the operator obtains an indication of apparent stress at the points where cracks first form in the coating. Thus the coating indicates the distribution of all tensile strains equalling or exceeding the rupture value for the coating over the entire surface. To obtain quantitative data, coatings that crack at different amounts of strain are used for identical tests. Comparison of crack pattern density on the specimen with crack density formed on the calibration strip under known strain shows approximate levels of strain.

To photograph the crack patterns in the coating for later study or record, either of two techniques are used: (1) The object is dipped in red dye etchant. The coating is then washed off, leaving the etched lines. (2) For quick, and generally adequate, results, the areas of crack formations are circled with crayon. Within these areas a few crayon marks are made, oriented with the cracks.

EQUIPMENT

Stresscoat unit shown costs about $1,000 and includes spraying equipment, a selection of coatings, thinner, and calibrating equipment. Over 20 coatings are available, so that for any temperature and humidity conditions there are coatings of several strain sensitivities.

Purchasers within Continental USA are entitled to the services of an instructor who will work with their engineers for several days. Brittle coating material to replenish original stock in the unit costs $7.50 per quart.

Loads are applied two ways:

1. Service testing, by using the coated part as a normal member of the machine through a cycle of operation.

2. Laboratory testing that simulates the service condition, but allows application of increments of load. This can be done with a loading pan, or by a press.

The hydraulic, hand-operated, automotive repair press, costing approximately $150, is excellent equipment for many tests. An ordinary pressure gage gives reasonably accurate measurement of load. Insofar as possible the load should be applied at the same points and with the same direction as the service load; otherwise stress distribution will not reflect service conditions.

Usual procedure is to load by known increments while watching for the formation of initial patterns. Two separate runs or more are often made; the first, to get an idea of what to expect; the second, to determine the exact load corresponding to a certain stage of pattern formation.

ADVANTAGES

1. Brittle coating has been remarkable, even startling, for its revelation of stress concentrations heretofore unappreciated. The tendency for strong sections to pass the load on to weak regions is strikingly revealed.

2. The powerful visual impression given by the crack patterns quickly emphasizes what design features are causing stress concentrations. Thus, one test may make obvious the path of

** Trademark of brittle coating equipment manufacturing by the Magnaflx Corporation.*

conveying the idea of stress distribution to shop men and other nontechnical personnel, by whom it can be easily understood and appreciated.

3. Stress distribution is obtained for an entire surface; therefore it provides a useful preliminary study of structure indicating where wire and other strain gages should be placed.

4. Small, critical regions around joints, fillets and holes can be studied because every part of the coating is an active indicator of strain. The working "gage length" is about $\frac{1}{16}$ in., and indicates peak stresses in regions where a wire gage would overlap and read an average stress. However, it may be hard to coat these regions with the identical thickness deposited on the calibration strip.

5. Residual stress values often can be approximated quickly.

LIMITATIONS

1. There is no time scale. When operated under service conditions, maximum stress only is indicated during cyclic loading.

2. Only one loading condition can be applied to a coating because the patterns cannot be erased. For another loading condition, or if an uncorrectable error is made during the running of the test, the old coating must be removed and another applied.

3. One of the biggest objections has been the need to operate in a narrow range of controlled temperatures and humidities. However, new coatings have broadened the useful temperature range and humidity is no longer critical. Stresscoat can be used under a wider range of conditions than generally supposed.

4. Quantitative readings have proven difficult for some experimenters. Accuracy better than 20–25 percent or within 5,000 psi in steel requires skill and experience.

REFERENCES

"Brittle Coatings for Quantitative Strain Measurements" by DeForest, Ellis and Stern, *Journal of Applied Mechanics*, Dec. 1942. In PRODUCT ENGINEERING a coming article by A. J. Durelli will cover brittle coatings as a complete system of stress analysis, and will include an exhaustive bibliography. Future articles by Greer Ellis will show how brittle coatings can be used under field conditions to study structural failures on the spot.

TYPES OF BRITTLE COATING TESTS
...and What They Revealed

1 A Full Cycle Service Test

PROBLEM: To determine whether a standard .38 special caliber revolver could safely handle the .357 Magnum load. Also to decide where stresses are greatest on the revolver cylinder; in the milled-out portion, on the periphery, or in the web between chambers.

METHOD: Revolvers were prepared with a coating, then fired with their respective cartridges. This was repeated with coatings of different sensitivities.

Stress levels noted were indicated by tests with coatings of different sensitivities
Cal. 38 Special
Frame stress 25,000 psi
Cylinder stress 25,000 psi
Cal. 357 Magnum
Frame stress 50,000 psi
Cylinder stress 50,000 psi
Cal. 38 Special
Cal. 357

Colt's Patent Fire Arms Manufacturing Company

RESULTS:

1. Highest stresses occurred in the milled-out portion of the cylinder, rather than in the web between chambers as had been suspected. Therefore the chamber spacing, which determines cylinder diameter and, in turn, frame size and weight, did not have to be increased to handle the heavier load.

2. Intensity of the cracks near the juncture of strap and barrel indicate that the frame must be strengthened.

2 Stress Distribution in Overload . . .

PROBLEM: To discover possible sources of failure, under heavy overload, in the gear case housing of an automatic home laundry. It was considered desirable to keep all stresses under 15,000 psi for this particular gray iron.

METHOD: Several castings were sprayed with coatings that cracked at strains corresponding to 14,000 psi and 20,000 psi in this gray iron. Coated castings were then operated in the machines under heavy overload.

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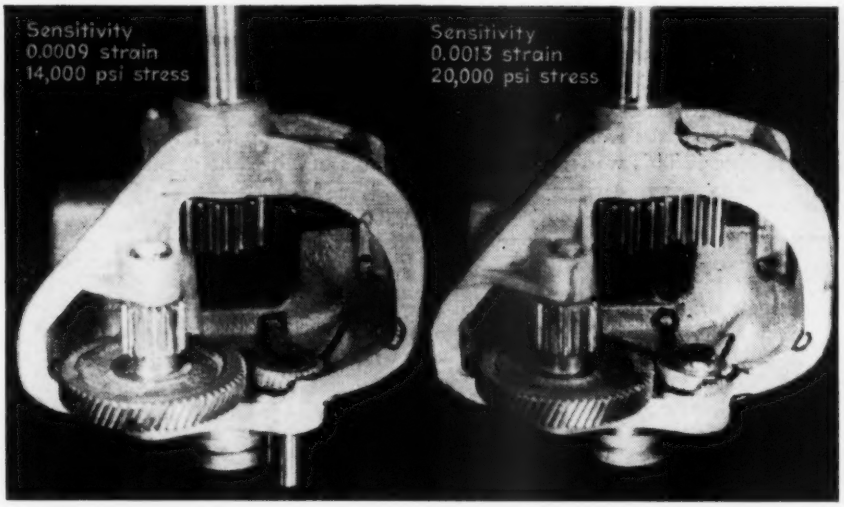
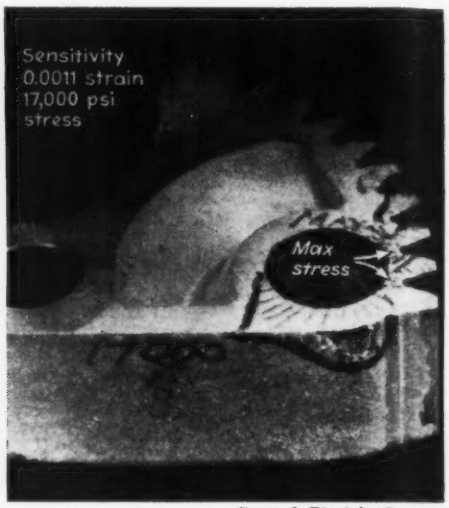




General Electric Company

TEST RESULTS: Crack pattern areas indicating approximately 14,000 psi or more and 20,000 psi or more are outlined in ink or crayon. Lines of crayon marks indicate direction of the cracks, which are too small to be seen in most photographs or their reproductions.

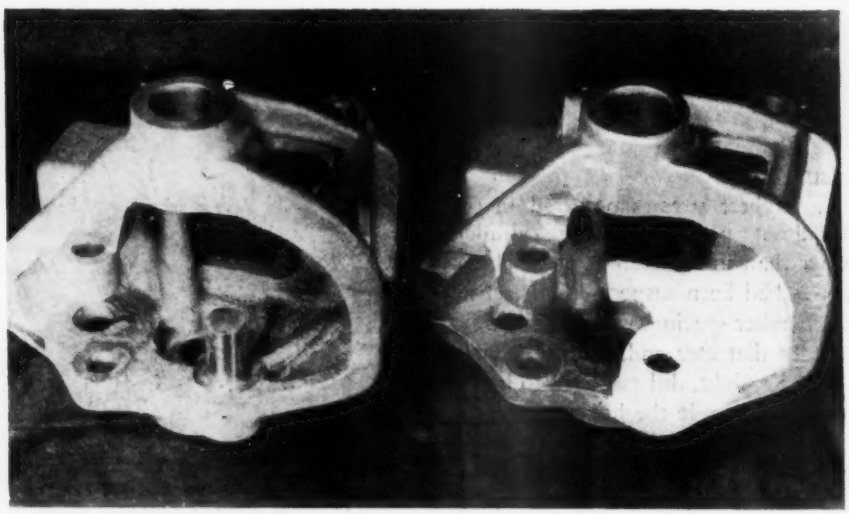
Tendency toward stress concentrations in corners is clearly shown. The brittle coating analysis also reveals that stiffening ribs are dangerous "stress raisers" because their outermost fibers are far removed from the neutral axis. It can be seen that an electric strain gage and most mechanical gages will overlap some of these stressed areas, thus reading average stress instead of peak stress.

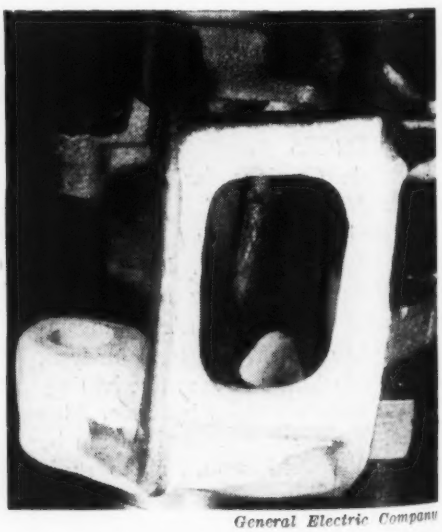
Stress lines along the rear faces of gear teeth on the rear of the sector gear indicate that there is insufficient metal in this region of the sector to handle the inertia force at the reversal of impeller movement.

• • •

DESIGN RECOMMENDATIONS: Casing on the right has been modified by plaster-of-Paris additions to show recommended changes from the original on the left. Boss support has been thickened and ribs are faired into smooth contours. A 45 deg, $\frac{1}{32}$ in. chamfer has been cut in the top of the boss support. This is expected to get maximum stress away from the 90 deg edge of the boss. Section on the bottom has been increased to add stiffness and reduce stresses. The pin dia has been decreased $\frac{1}{2}$ in. to help in reducing stresses on the thin left side of the boss.

Sector gear was strengthened by increasing the metal in the area of excessive stresses.





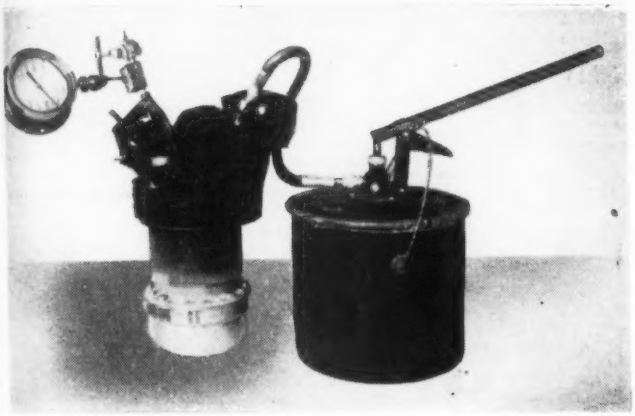
General Electric Company

3 Fillet Stress Study . . .

PROBLEM: To determine the cause of failure of an aircraft engine cylinder; this failure caused the plane to crash, killing a number of passengers. Failure was in the cylinder wall just above the flange. Independent experts held four different opinions on the cause:

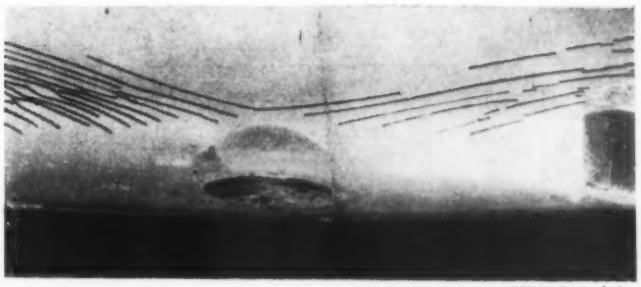
1. Started in the small fillet behind the cylinder hold-down nut because of rough machining and stress concentrations.
2. Started at the stud hole in the flange.
3. Started in cylinder wall just above main fillet because hold-down stud was loose.
4. Started as in (3) but caused by "dirt" in the steel.

METHOD: Hydraulic press was used to apply pressure to the explosion chamber. About 45,000 psi, the high tension stress during takeoff, was produced in a perfect cylinder and in a deformed cylinder, both brittle coated.



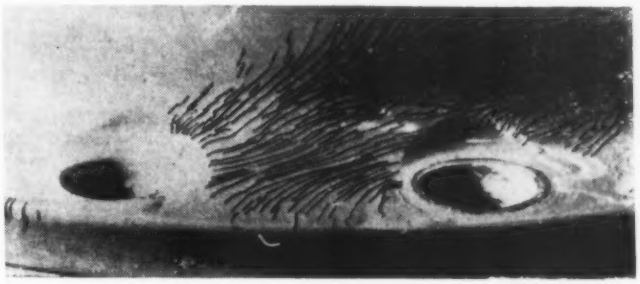
Ellis Associates

TEST RESULTS:



Ellis Associates

PERFECT CYLINDER: Patterns showed that fillet, hole, and even absence of a stud, were not the cause of failure.



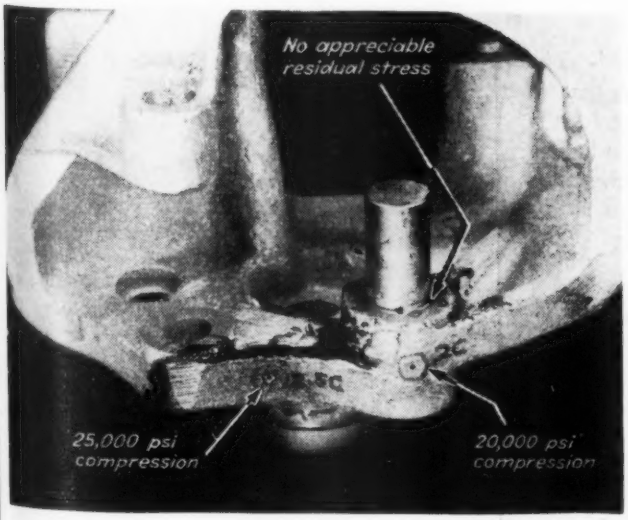
Ellis Associates

DEFORMED CYLINDER: (Outer edge of flange was bent upward 0.01 in. above the inner edge.) Cracks showed residual stresses of at least 65,000 psi existed before the hydraulic loading.

CONCLUSIONS: A cylinder from the engine in question was tested and gave results similar to those of the deformed cylinder. A check on the records showed that the engine had been in a minor previous crash, which had sprung the cylinders out of line. The possibility of flange misalignment never had been considered. Thus, an unsuspected cause of failure was detected and a hypothesis confirmed.

4 Residual Stress Determination . . .

PROBLEM: To study residual stresses in the gear casing described in Test 2.



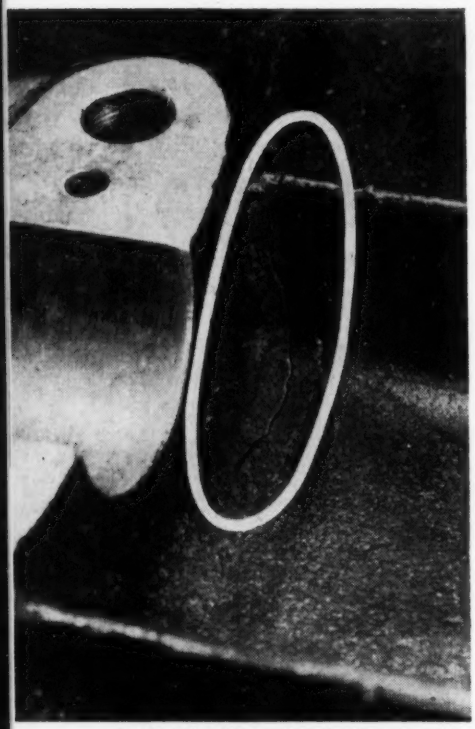
General Electric Company

METHOD: Coating having a sensitivity of 0.0005 in. per in. strain was applied. After drying, holes were drilled in the casting with a depth approximately equal to the dia of the drill, $\frac{3}{64}$ in., in this test. If strains exceeding the coating rating are relieved, patterns will form in the coating. Radial cracks reflect tensile stresses, circular cracks indicate compression. The extent of definite pattern away from the edge of the hole in terms of the number of diameters of the hole gives a measure of the residual stress present.

TEST RESULTS: Each diameter of pattern, which in this instance is each crack ring, represents approximately 10,000 psi of residual compression. The notation "2C" means 2 rings of cracks. The push fit of the pin probably has relieved compressive stresses in the pin boss.

Note: The accuracy of this method is admittedly in need of more analysis. However, there is certainly a rough quantitative indication by this technique. The reader is referred to the writings of A. J. Durelli and Greer Ellis in Mechanical Engineering, Dec. 1947, 1049-50.

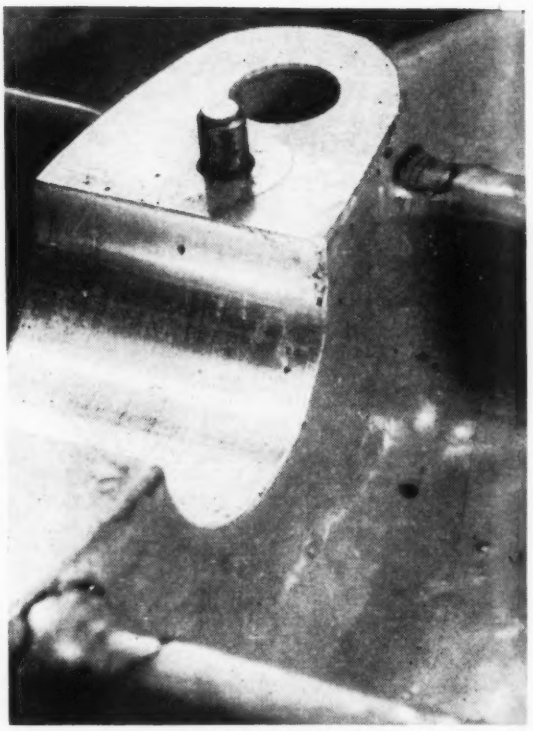
5 Avoidance of Stress Raising Design Features



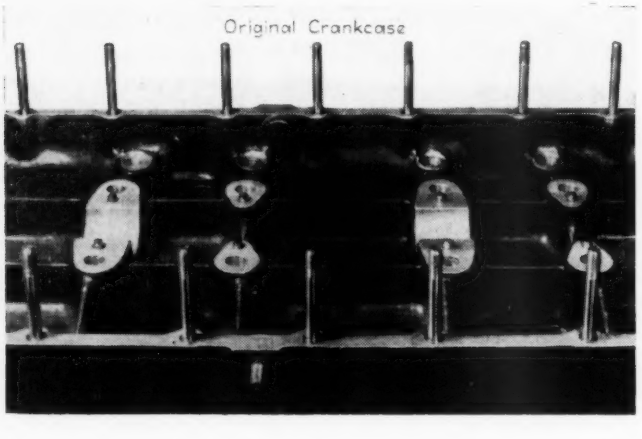
Continental Aviation and Engineering Corporation

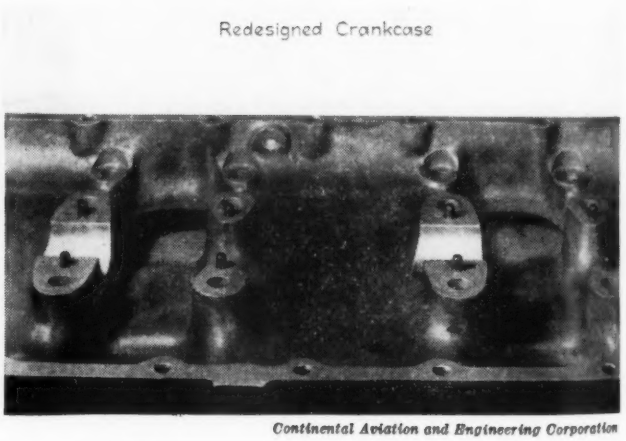
PROBLEM: To develop an aluminum or magnesium crankcase that would have the minimum material, with adequate strength. The crankcase bays should be shapes easily cast. It should be possible to add the basic bay pattern to the 4 cylinder crankcase so that the crankcase could be extended for 6 or 8 cylinder engine designs.

METHOD: Failure occurred at the upper corner of the stiffening rib. The crack (left) started where the fibers were under maximum stress because of their distance from the neutral axis and stress concentrations in the fillet. Brittle coating test (right) revealed the high stress concentration in this region.



Continental Aviation and Engineering Corporation

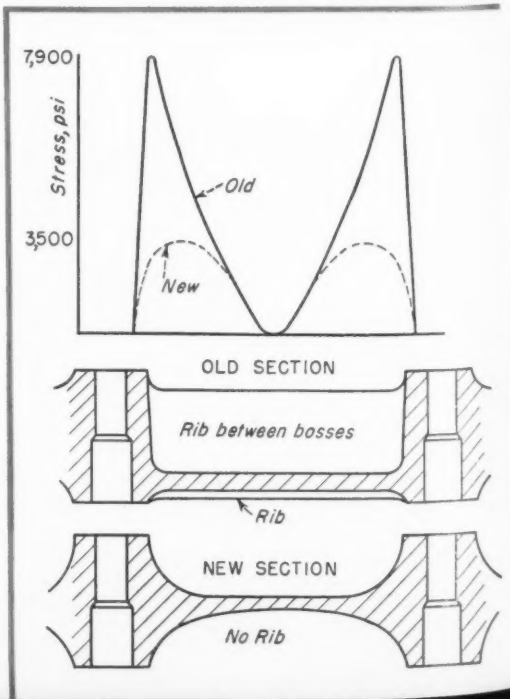




Continental Aviation and Engineering Corporation

RESULTS: Original casting on the left was modified to the shape shown on the right. Longitudinal ribs have been eliminated. The crankcase web is raised nearer the middle of the boss depth so that all fibers are closer to the neutral axis. All contours are flared gradually into other sections. Overall effect is that of a sheet drawn into appropriate shape, and strengthened by thickening where needed, rather than by the addition of other members.

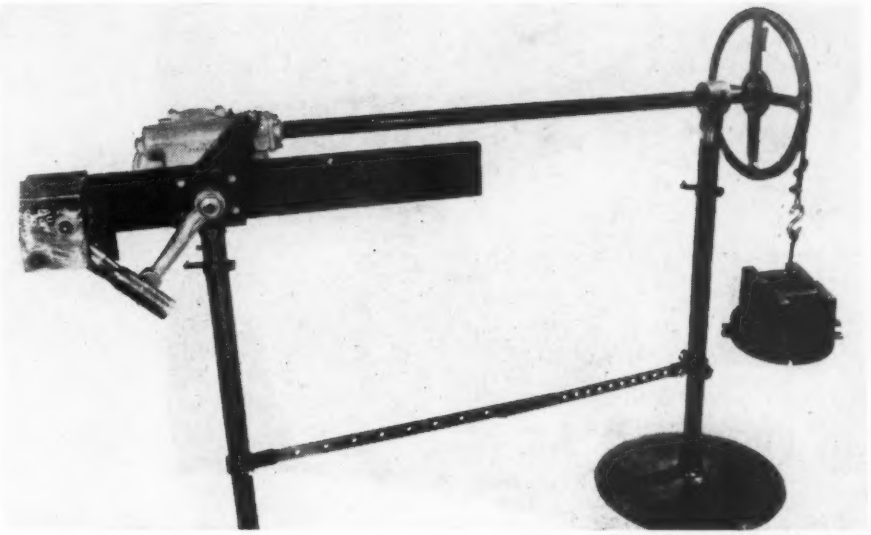
COMPARATIVE PERFORMANCE: Can be visualized from the drawing at the right. The highest stresses occurred in the old design where the narrow rib and boss were joined by a fillet. This point also is far removed from the bending axis. The stiffness of this high rib prevents intermediate flexure that might relieve the bending load on the fillet. The new design avoids this danger spot. Peak stress concentrations have been reduced over 50 percent. The stress gradient is much more gradual in the new design. The new crankcase is almost 20 percent lighter; strength has been proven in repeated service tests.



6 Preliminary to Wire Strain Gage Analysis

PROBLEM: To obtain information useful in the design of steering gear housings.

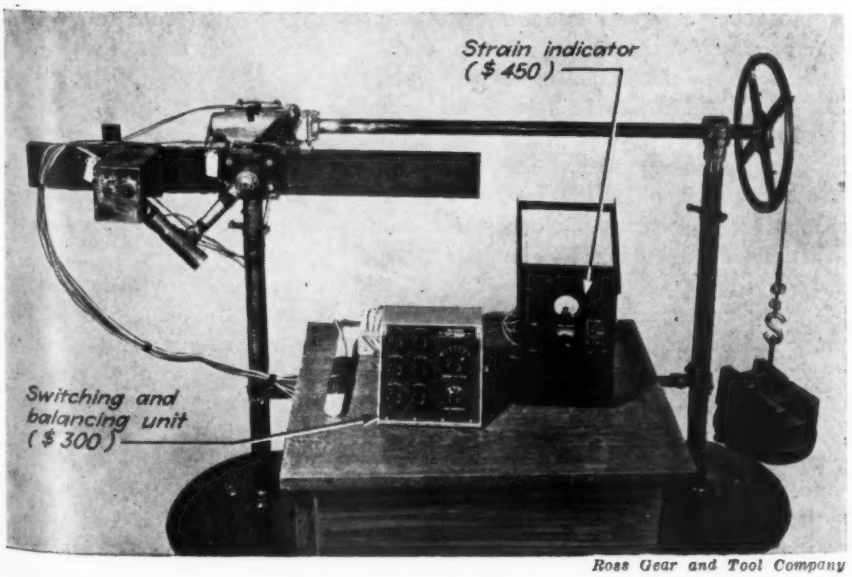
METHOD: Cast aluminum alloy housing and steering arm of SAE 4130 steel were brittle coated then statically loaded in the homemade rig shown. Starting with an initial 5 lb, dead weight loads were applied in 6 increments of 25 lb and one of 30 pounds. This 185 lb load corresponds to a torque of 1,665 in-lb, about maximum torque exerted by a driver. Critical areas revealed by the brittle coating were then studied with wire strain gages of the SR-4 type.



Ross Gear and Tool Company

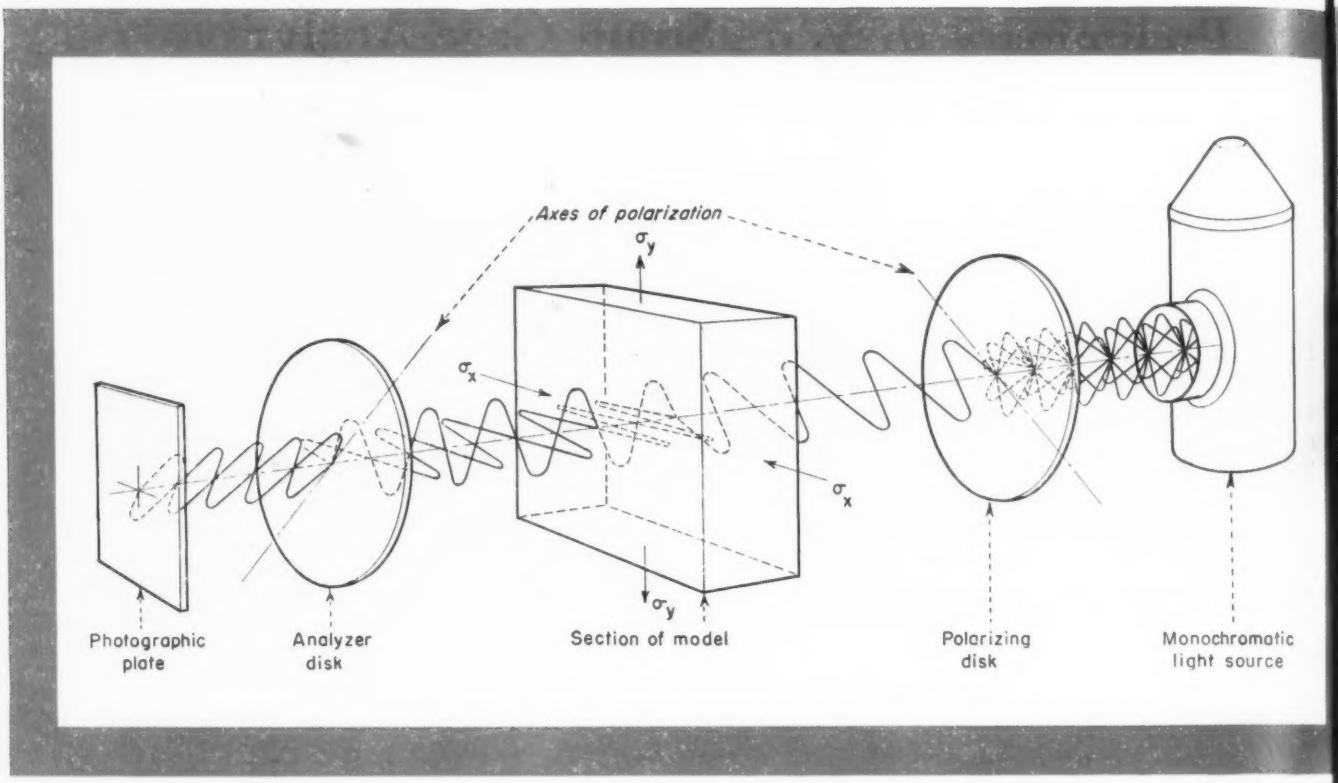
Ross Gear and Tool Company

RESULTS: (Steering arm only shown.) Almost entire arm was covered with crack patterns. Estimated maximum stress was 69,000 psi tensile, at *D* in the figure. Numbers on the steering arm show extent of pattern for that many pounds on the loading platform. After brittle coating tests revealed the stress distribution, the unit was then tested under identical loading while six wire strain gages were cemented to the arm and housing regions most critically stressed.



Ross Gear and Tool Company

RESULTS OF WIRE GAGE TEST: Maximum stress at point *D* was 62,700 psi tensile, confirming the Stresscoat reading. No glaring design weakness in the steering arms was revealed, as the ultimate strength of the SAE 4130 is 120,000 psi with this particular heat-treatment. Housing test results, while showing no high stress concentrations, suggested that working stresses were a bit high for cast aluminum and might cause failure through fatigue.



Photoelasticity

PRINCIPLE

Stress analysis by photoelasticity is based upon the property of certain transparent materials to be doubly refractive under stress. Polarized light passing through such material vibrates in two perpendicular planes, the planes of principal stresses in the model at each point. The velocity of light through the model is a function of the intensity of the principal stresses. Thus interference bands that can be interpreted as stresses are produced. Stress conditions in the model generally are identical to conditions in the full-sized unit under similar load.

METHOD

After the model is placed under load, polarized light is passed through it. The interference pattern can be seen on a ground glass, and it is usually photographed for later study. Two characteristics are important for design purposes: (1) Difference of the principal stresses—obtained from the isochromatic lines. These are lines of constant color if a white light source is used, or are a series of dark and light lines with a monochromatic light source. (2) Direction of the principal stresses—given by the isoclinic lines. These are dark lines that connect all points in the model at which principal stress directions are parallel to the axis of the polarizer or analyzer disk.

Often stresses at the free edges of the model are the only concern. At free boundaries the normal stress, which is one of the principal stresses, must be zero. Then the difference in principal stresses is equal in magnitude to the tangential edge stress. This difference is computed by multiplying a constant for the particular model material times the number of isochromatics (fringe order) between the edge and the interior spot that stays dark during all the loading; then dividing by the thickness of the material in the path of the light.

Contemplated design changes can be checked for stress distribution by photoelastic examination of a new model, or study of the old one after modifying the contour with a file.

ADVANTAGES

Photoelastic stress analysis has certain advantages:

1. Gives stress distribution throughout a section, not only at the surface. Its most important application is in the determination of stress concentration factors.

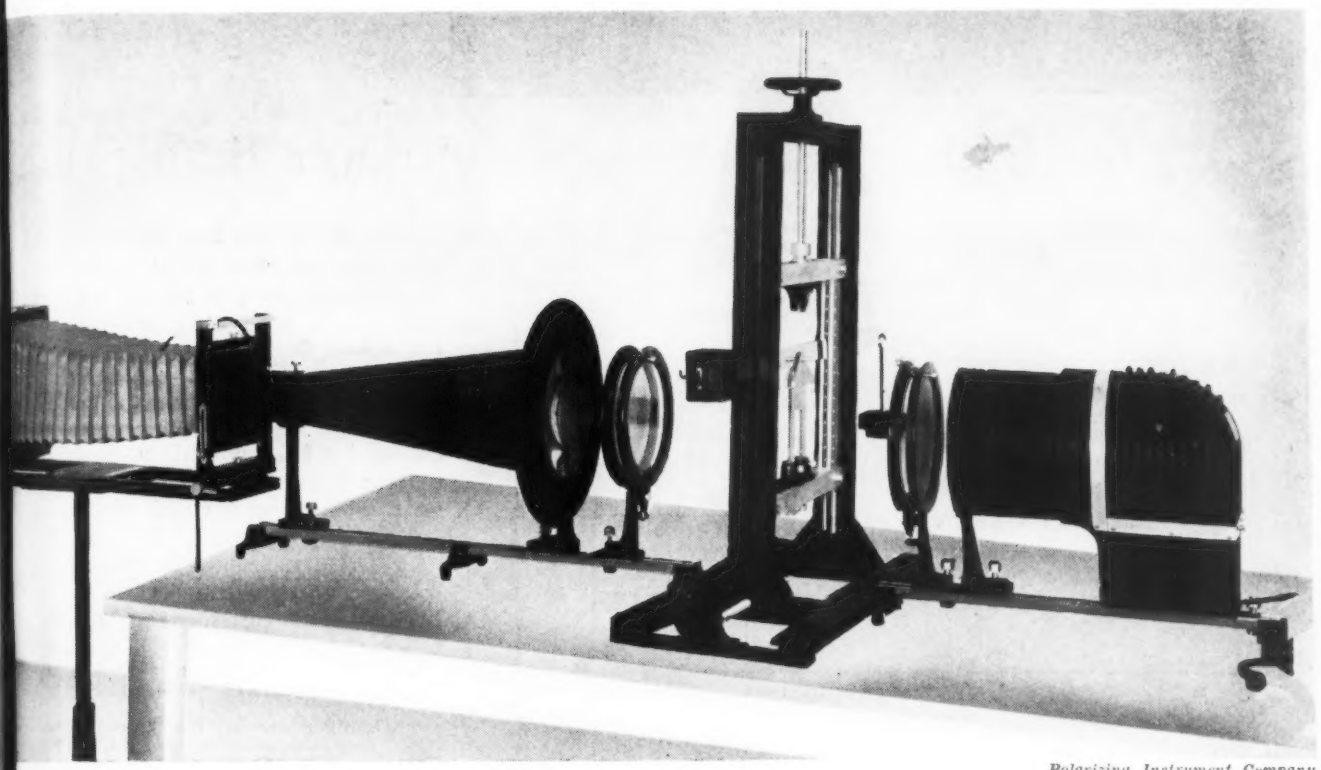
2. Indicates stresses in otherwise inaccessible parts; for instance, where machine members meet and the mating surfaces cannot be reached by gages or coatings. Probably the best way of studying localized compressive stresses.

3. Tests can be completed and modifications studied in inexpensive models, before the full-sized unit is made.

4. Where quantitative determination is practical, the value of stress at a point can be obtained. In this sense the method is equivalent to a strain gage of zero length.

LIMITATIONS

The operator must be well grounded in higher mathematics for much quantitative work. However, for practical



Polarizing Instrument Company

design work all he has to know is how to count fringes and apply this information. Other difficulties:

1. Two dimensional models, customarily used, do not always accurately reflect conditions in the three dimensional reality.

2. Three dimensional analysis is beyond the capabilities of the average small engineering group.

3. Dynamic and impact values are hard to get and may be questionable.

EQUIPMENT

Years ago the cost of photoelasticity equipment was almost prohibitive, but since the development of modern plastics, polarizing materials have become quite reasonable. There are only five elements to a photoelasticity setup: a light source, condensing lens, polarizing medium, the model and a device to load the models, and a camera.

Light Source: An ordinary incandescent bulb can be used although monochromatic light is a desirable refinement. A mercury vapor lamp and filter, which gives monochromatic light, costs about $20.

Condensing Lens: This is required to focus the rays on the model. Cost will be roughly proportional to the square of the diameter. The size of lens required depends upon the field desired. A 6 in. field is about minimum, with 10 inches a much more useful size. High precision is not essential in the lens for most design work. A 10 in. lens, obtainable from companies making optical instruments, might cost $60.

Polarizing Medium: Two glass plates or two plastic sheets can be used. If mounted by the experimenter the cost will be reduced. Polaroid film will scratch in time, but it is the cheapest medium, $12 per sq foot. Polaroid glass is best for any permanent equipment, $40 per sq foot.

Model: Cast resin and other plastic materials are generally used, although celluloid, glass and other transparent materials can be used for qualitative work. Current price of cast resin for quantitative photoelasticity purposes is $14 per lb, and for qualitative work, $2 per pound.

The loading device will have to be built by the experimenter to suit the particular object and type of load.

Camera: Any camera capable of accurate focus at short distances is suitable. A plate back camera is often used.

Cost depends upon the size of the field desired, which determines the diameter required in lens and plates. Complete commercial equipment consisting of a photoelastic polariscope, loading frame and recording camera costs about $2,000 in an 8 in. aperture.

REFERENCES

"Photoelasticity," Vol I, by Max M. Frocht, John Wiley & Sons, Inc., 1941.

"Photoelasticity," Vol II, by Max M. Frocht, John Wiley & Sons, Inc., 1948.

"A Treatise on Photoelasticity" by E. G. Coker and L. N. G. Filon, Cambridge University Press, 1931. A scholarly work, now more of academic interest.

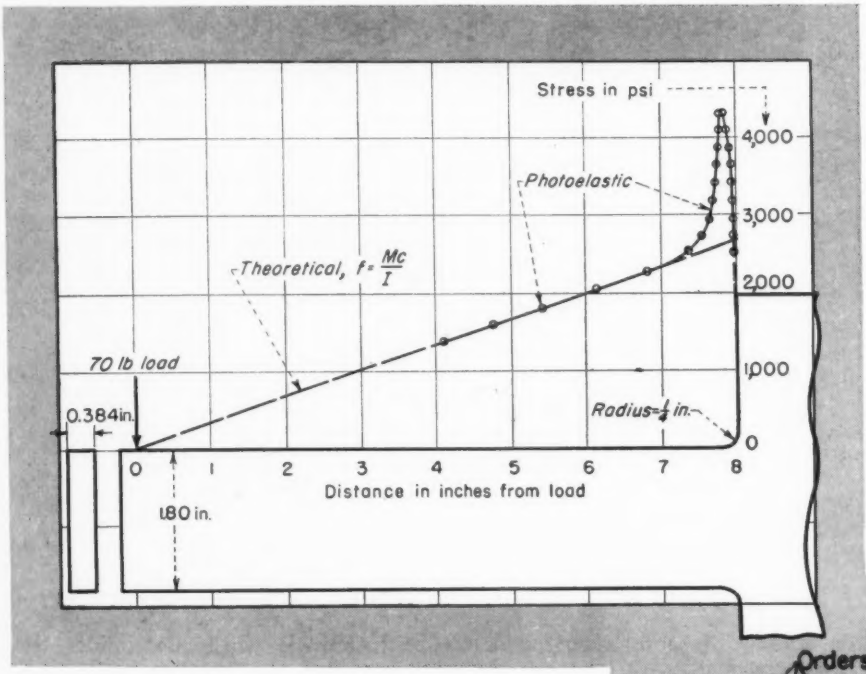
Information on the design of a complete photoelastic laboratory, as well as an excellent bibliography, is contained in an article by Dr. R. D. Mindlin in the *Journal of Applied Physics*, April, May, 1939.

Forthcoming articles in PRODUCT ENGINEERING will tell how to build and use a low cost, photoelastic polariscope, suitable for making many useful design investigations.

Other articles will show practical design applications of the photoelectric technique. Photoelastic analysis of stress-relieving fillet curves will be described next month.

TYPICAL PHOTOELASTIC STUDIES

1. Stress Distribution in a Simple Cantilever Beam



Equipment: Simple homemade polariscope, costing under $200.

Test Method: An 8 in. cantilever beam made of cast resin, carrying a concentrated load of 70 lb, as shown, gave the isochromatic stress pattern illustrated below. By counting the orders of interference from the zero reference it has been possible to establish the boundary stress at each point where the stress lines intersect the edge.

Stress on the free edge =

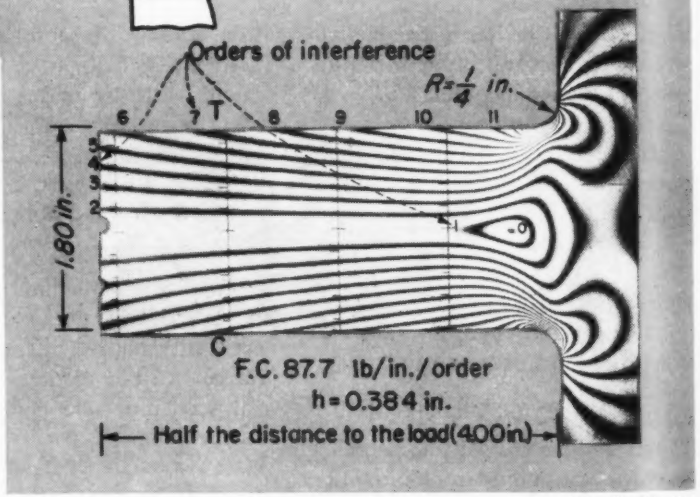
$$\frac{\text{F. C. (87.7)} \times \text{order of interference}}{\text{thickness (h = .384)}}$$

For example, corresponding to the eighth order of interference, stress on the free edge $= \frac{87.7 \times 8}{.384} = 1{,}825$ psi*.

* Actually represents the difference between the principal stresses, but in the free boundary one principal stress = 0.

Test Results:

1. Stresses along the model edge have been plotted and illustrate remarkable agreement between theory and experiment in the region where the beam theory is valid. However, in the vicinity of the fillet, where the theory does not apply, there is a wide discrepancy. Here actual stress is higher than predicted.
2. The ratio of the peak value of stress that actually occurs in the fillet to the maximum value computed from beam theory gives the stress concentration factor for these conditions.
3. By investigating a series of models, stress concentration factors for many conditions can be established for the designer's convenience.



W. M. Murray

THREE DIMENSIONAL ANALYSIS has been held back for lack of suitable material. Previously resins have been limited to about 1¼ in. thickness. Westinghouse now has a resin for three dimensional analysis in models up to about 6 in. diameter. The material is intended for "frozen stress" studies. In this technique the model is heated to about 240–260 F, then loaded and cooled slowly under load, to room temperature. Stresses are "frozen" in the material. The object is then sliced into whatever sections the observer wants to study. Stresses in each section are thus preserved for under polarized light.

Westinghouse Electric Corporation

2. Analysis of Stresses in a Bolt Head

PROBLEM: To develop a high fatigue strength bolt by redesign of juncture of bolt shank and head.

EQUIPMENT: Simple polariscope.

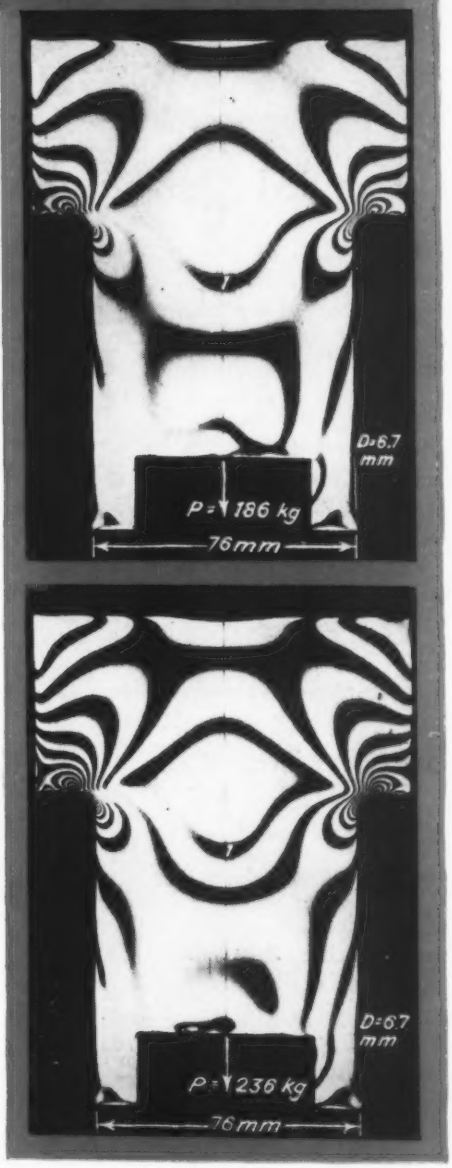
LOADING: Arrangement for static tension loading by 50 kg increments. As each increment is added, additional isochromatic lines develop. All represent lines along which the differences of the principal stresses are an identical value, although the stresses themselves are not the same.

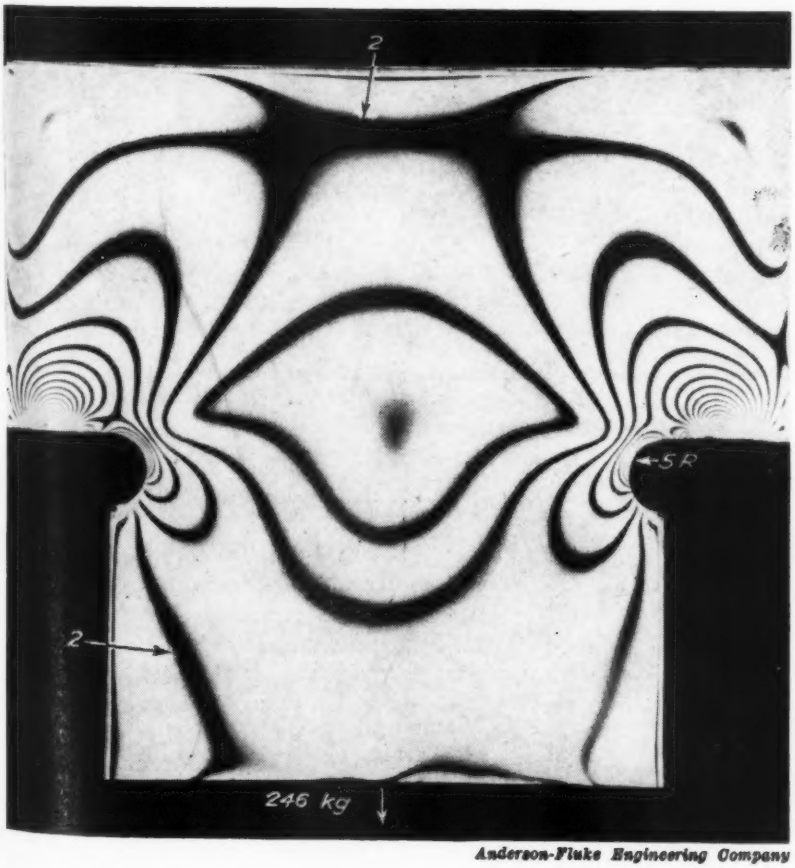
TEST RESULTS

INFORMATION GAINED:

1. The standard bolt develops high stress concentrations at the juncture of bolt head and shank. It was believed that fractures were partially caused by the abrupt change from tension in the shank to compression in the head. Although a true three dimensional effect is not given by this two dimensional model, the correspondence between stress concentrations in the model and fractures in actual bolt is close.

2. Final design evolved has a groove at the juncture of head and shank. As the photoelastic test shows the groove relieves stress concentration at this juncture and eases the transition of tension stresses into compression stresses.





Anderson-Fluke Engineering Company

Electric Strain Gages

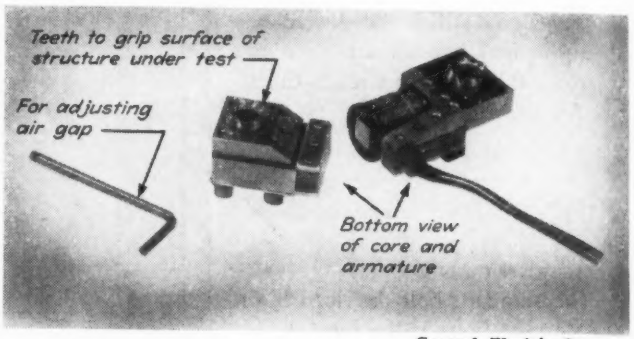
The accuracy of electric strain gages in indicating local surface conditions, their adaptability to all kinds of structures and materials, and the many ways in which their signals can be handled, make them the most important tool available to the stress analyst. Any place that a strain change takes place is a potential place for an electric strain gage, subject to certain limitations.

1. Three Types of Electric Strain Gages

Magnetic or Reluctance Type Gage

A laminated steel core wound with wire and a laminated steel armature are separately mounted on the specimen. Depending on the application, the air gap is adjusted from 0.003–0.025 in. by an eccentric screw. As the material is strained, change in the air gap causes a deflection on an oscillograph film. Magnetic strain gages are also made on the principle of the linear variable differential transformer. See *Proceedings* of the SESA, Vol IV, No. 2, p 79, for a description.

ADVANTAGES: High output, which frequently does not require amplification. Measures small displacements as well as strain. Durable. Generally applied permanently to bridges, tanks, rails, ship hulls and other large structures.



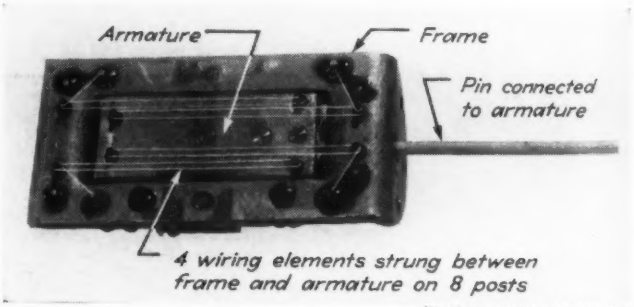
General Electric Company

LIMITATIONS: Its bulk and the necessity for screwing it to the work. Cost: $95, plus instrumentation.

Unbonded Resistance Wire Gage (Statham Type)

Operates on the same resistance change principle as the bonded gage (below). Four filaments are strung between posts on base and armature. The base is fixed to the member under test. Movement applied to pin P causes the armature to move, stretching the filaments.

ADVANTAGES: Measures ± 1,500 microinches rather than microinches per inch. It is best used to measure displacements. Measures small loads of 5–10 grams and low pressures. Because the filament wire can be made to carry the load, it has high sensitivity and high electrical output. Below 2,000 psi the gage has a definite advantage over the bonded type for direct indication.



Statham Laboratories Inc.

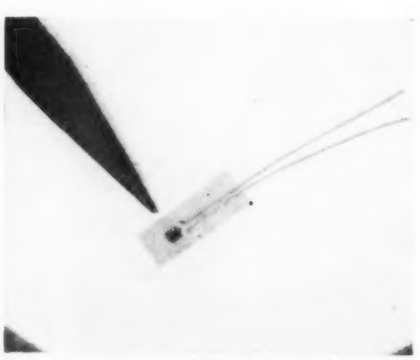
LIMITATIONS: Necessity of screwing or clamping the bases to the material under test; accordingly, it is not well suited to measurement of surface strains. Cost: About $65. Instrumentation is similar to the bonded-gage equipment.

Bonded Resistance Wire Gage (SR-4)*

A. Operational Principle

Operation is based upon the change in the electrical resistance of a fine wire as it changes in length. The gage comprises a filament 0.001 in. dia cemented as a grid on a paper less than 0.001 in. thick. Theoretically, the wire is encased in a matrix of cement having a low modulus of elasticity compared to the filament. This restrains the wire throughout its length so that it does not buckle under compression loads. A piece of felt is cemented over the wire for protection.

In use, the paper containing the filament is cemented to the surface at a point under investigation. As the surface is strained, the length of the grid is changed identically. The change in the electrical resistance and, therefore, the deformation, can be translated by suitable calibration into strain, deflection, acceleration, temperature, pressure, torque, or load.



Baldwin Locomotive Works

* *Trademark Reg. U. S. Patent Office*

B. Advantages and Limitations

1. The gage is extremely close to the surface so that it will measure the strain more accurately than gages that project above the surface; important for thin members in bending.

2. Under carefully controlled conditions it measures in millionths of an inch per inch, which is about ten times the sensitivity of many mechanical extensometers. Useful for strains up to one percent or more.

3. The gages are so cheap that they can be used profusely, although their use is limited to suitable recording equipment which is expensive for elaborate setups. Equipment cost is a nonrepetitive expense, however.

4. The gages are so light that they rarely change the balance or the natural frequency of objects to which they are applied.

5. Because of their small size, they will not affect the aerodynamic characteristics of an object if properly applied. They can be used in wind tunnels or for other fluid studies.

6. They are remote indicating and their responses can be recorded, photographed, sent by radio, or amplified for control purposes.

7. They can be sealed into a part during fabrication or can be mounted in many confined spaces because of their small size.

8. Paper mounted gages are serviceable to 175 F and will sustain 250 F temperatures. Bakelite mounted gages are useful at 350 F continuously and 500 F for short periods.

9. They have freedom from hysteresis, and have low creep values when properly installed.

10. They operate well beyond the elastic limit (up to 1 percent strains) without altering the original calibration, enabling structures to be analyzed to failure.

11. They can be used for vibrations up to 30,000 cps, perhaps higher, which adapts them to fatigue studies.

12. Calibration is stable under shock loads, explosive forces with steep wave fronts, or severe vibrations.

LIMITATIONS:

1. Low output, which must be amplified for some purposes, especially for dynamic studies.

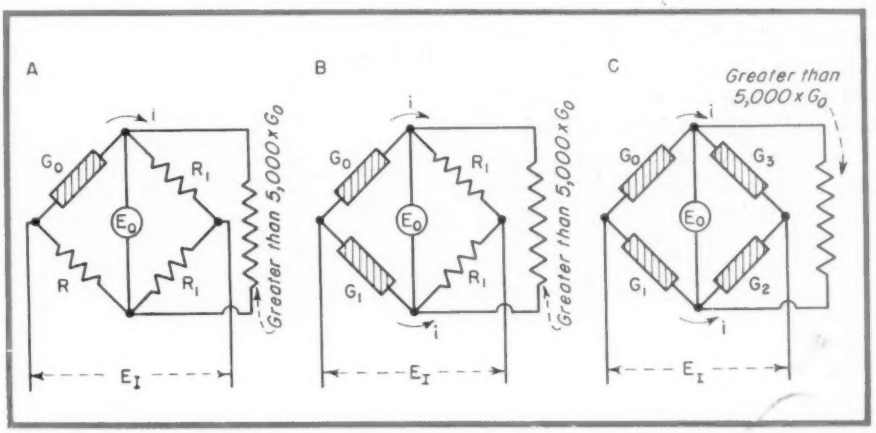
2. High first cost of instrumentation, particularly for multiple recordings and dynamic studies.

3. To handle a complicated stress study requires more than a casual knowledge of electronic instrumentation, particularly for dynamic studies.

COSTS: Gages run from 69¢ to $12.75. Most commonly used gages are less than $1 apiece in quantity. Instrumentation costs depend upon the problem.

C. Basic Circuits

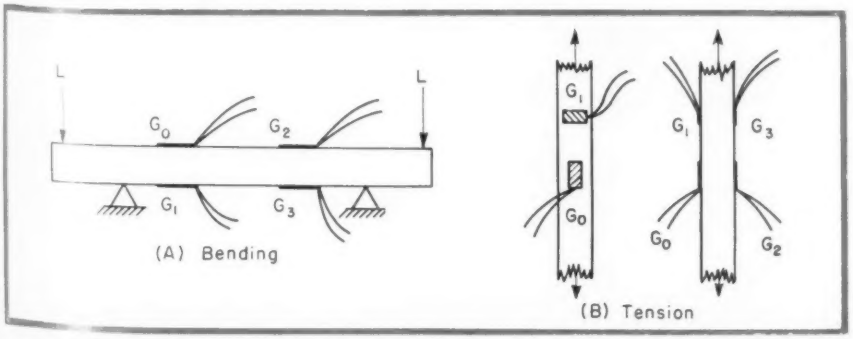
Gage circuits are based on the Wheatstone bridge with one, two or four active gages. Gages are placed parallel to the directions of strains to be measured, if known. (Otherwise rosette forms of gages can be used.) Input voltage, E_I, may be direct or alternating current. Circuit (a) provides no temperature compensation. Circuit (b) compensates for temperature by using G_1 at the temperature of G_0, but without allowing strain change in G_1. Bridge output is the proportional to strain change only, if compensated. Circuit (b) also can be used to double bridge output by placing G_0 and G_1 on opposite sides of a member, when strain in G_0 is opposite in sign to strain in G_1, as in bending. Circuit (c) is sometimes used to secure four times the bridge output of circuit (b), or four times the sensitivity.



Principles shown above are covered by patents controlled by The Baldwin Locomotive Works.

D. Design Data That Can Be Determined

Strain—Read directly in some instruments; or calibrated in terms of voltage.



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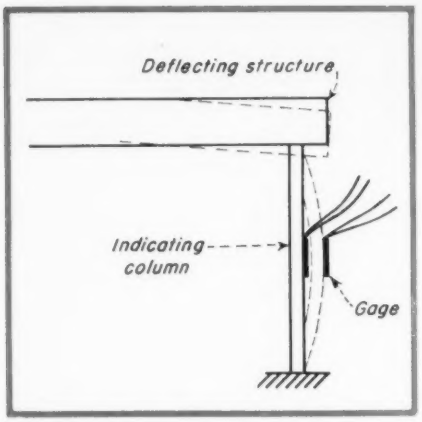
Stress—Computed from strain.

Load—The gage is placed on any appropriate portion of the structure or on a lever or compression block attached to the structure. Calibrated by plotting gage output against known loads. Generally practical only when calibration under known loads is possible.

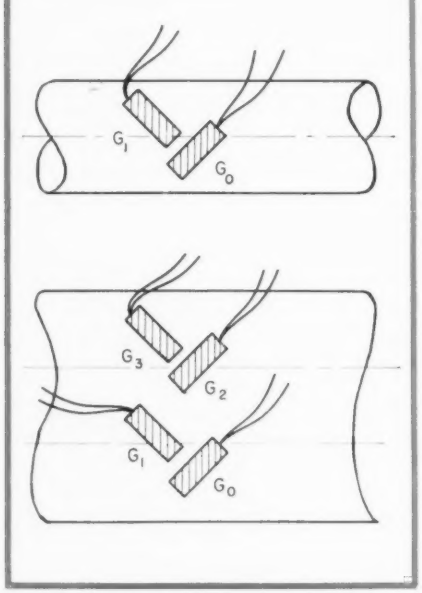
Pressure—Gage is mounted on the circumference of the pressure vessel, usually a small pipe. Amount of strain in the known material is calibrated in terms of pressure, or calibrated by plotting gage output against known pressures.

Deflection—Obtained by calibrating the bending of a beam which is loaded by the deflection under examination. This enables a small deflection to be detected. Calibration of beam carrying gage is done with any convenient arrangement for imposing known loads.

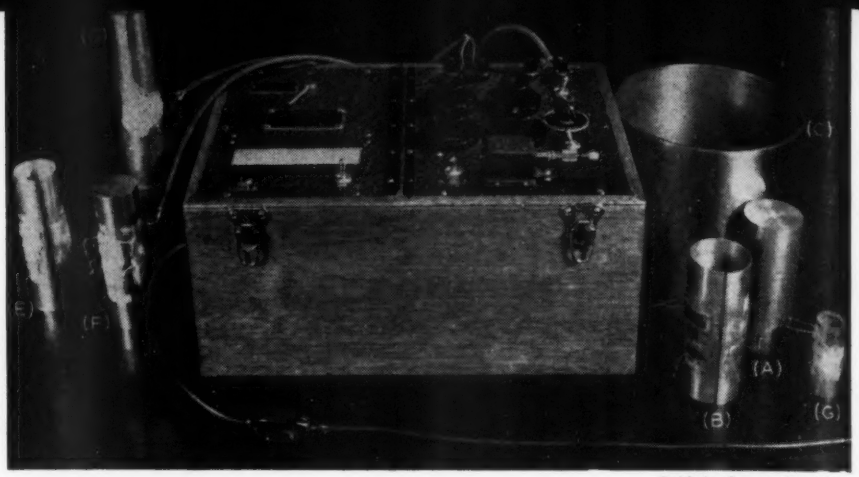


Principles shown here and for "Torque" are covered by patents controlled by the Baldwin Locomotive Works.

Torque—Two gages are spatially arranged on 45 deg right-hand and two on 45 deg left-hand spirals on opposite sides of a circular shaft. Pure tension and pure compression strains are thus indicated and can be translated into torque. This arrangement is temperature compensated and independent of bending and direct thrust effects.



Direction and Magnitude of Principal Strains—A biaxial stress field is measured by a rosette type of strain gage that indicates 3 components at definite angles. Computation determines direction, if unknown, and magnitude of principal strains.



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Residual Stress Determination—Indicated by a gage cemented on the desired spot, as surrounding material is cut away, thus allowing material under the gage to relax. Resulting strains reflect original residual stress. (A) Specimen before boring-out and final slitting. (B), (E) After boring-out and final slitting. (D) Specimen carrying dummy gage.

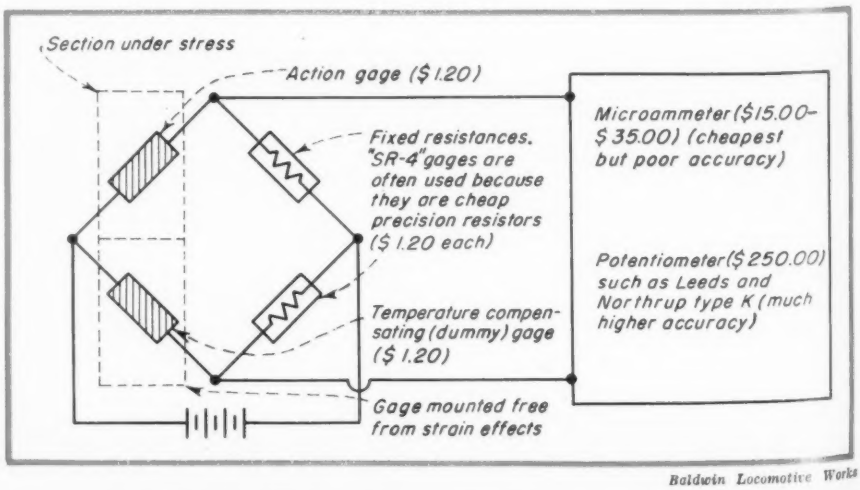
2. Instrumentation

Type and cost of instrumentation depends upon: (1) Whether the test is for static or dynamic readings. (2) The level of accuracy required. (3) Number of readings to be taken. For a few readings over a large time period, manual balancing indication is adequate. For simultaneous readings at many points, more observers are required. To save man hours, or to take many readings in a short time, automatic recording is needed. (4) Duration of the test setup. Better instrumentation is required if readings are to be taken over a period of months. (5) Test conditions. Laboratory and field studies may require different equipment in terms of portability and accuracy.

It is a misconception that the purchase of each new instrument enables the operator to obtain a new kind of data. This distinction is generally true only between static and dynamic studies. Otherwise the purpose of additional instrumentation is largely (1) to save time and (2) to make a record. Minimum setup for static studies, as shown, can be used to interpret strain into almost any kind of primary cause, limited only by number of readings and accuracy required.

A. Minimum Setup Using Microammeter or Potentiometer

Four gages, connected as a Wheatstone bridge, secure a high sensitivity because more than one gage can be active. Total cost is $60 to $250, depending upon the instrument used. Limitations: (1) Data must be interpreted into a strain by calculation or by calibration. (2) Voltage changes in the battery affect sensitivity and accuracy. (3) Handles only one bridge at a time.


Section under stress
Action gage ($1.20)
Fixed resistances. "SR-4" gages are often used because they are cheap precision resistors ($1.20 each)
Temperature compensating (dummy) gage ($1.20)
Gage mounted free from strain effects
Microammeter ($15.00–$35.00) (cheapest but poor accuracy)
Potentiometer ($250.00) such as Leeds and Northrup type K (much higher accuracy)

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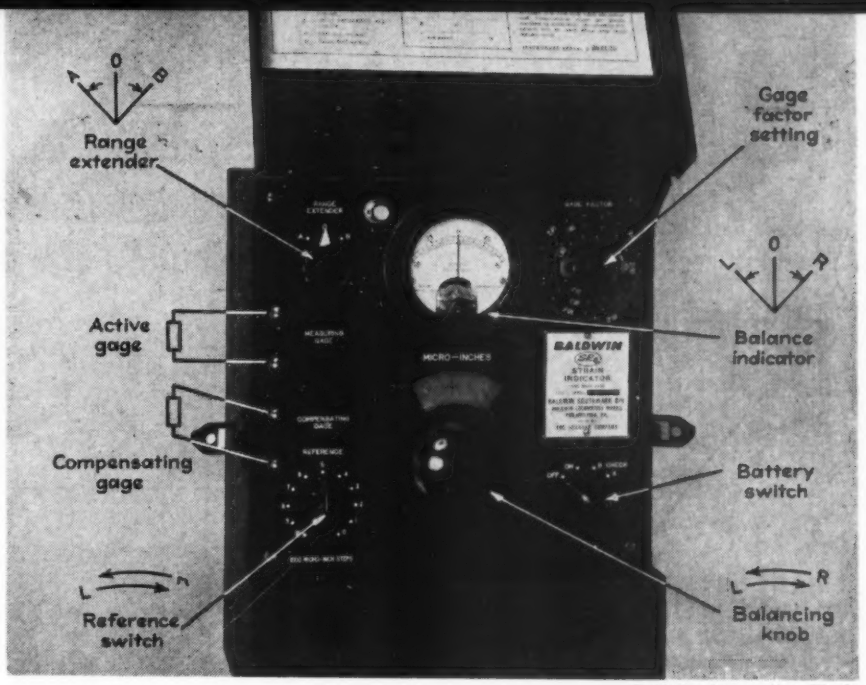
B. Minimum Setup for Direct Strain Indication

This typical portable battery operated instrument is calibrated to read in microinches of strain per inch. One or two active gages can be used. The effect of battery voltage is eliminated by the circuit. Because the scale is arranged to read in either direction, a change in the direction of strain can be observed. Cost: $450 approximately. There are several strain indicators made, some combine manual switching and automatic balancing. Limitations: (1) Only one gage or one half-bridge can be connected at any time. (2) Must be manually balanced before each reading.



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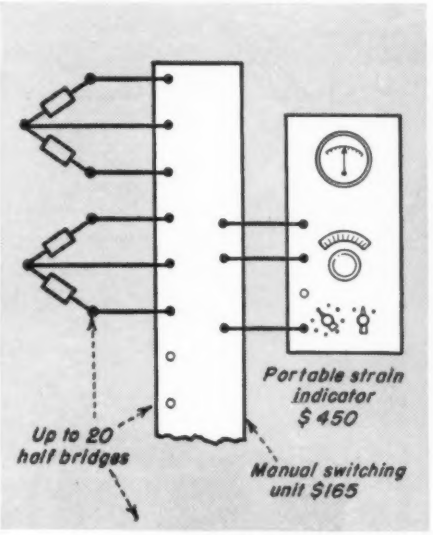
C. Reading Bridges in Rapid Succession

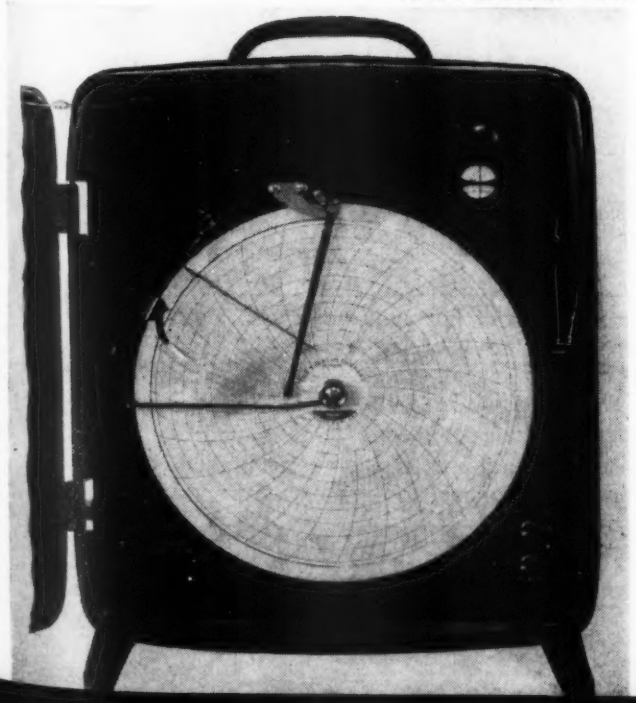
A manual switching unit for 20 bridges can be interposed between the gages and the strain indicator. Complete multiple gage strain indicators (right) automatically balancing up to 48 gages are available. These are the ultimate in convenience. Cost: $3,800. Limitations: With the manual switching unit, each strain reading must be subtracted from the initial datum level of that particular gage. These switches are available with initial balancing so that all bridges may be balanced to a common datum line prior to the test. Price varies with number of channels ($300 to $700 for 6 to 20 channels).



Baldwin Locomotive Works

Nosker Engineering Products

Baldwin Locomotive Works



D. To Record Strain Data from One Gage

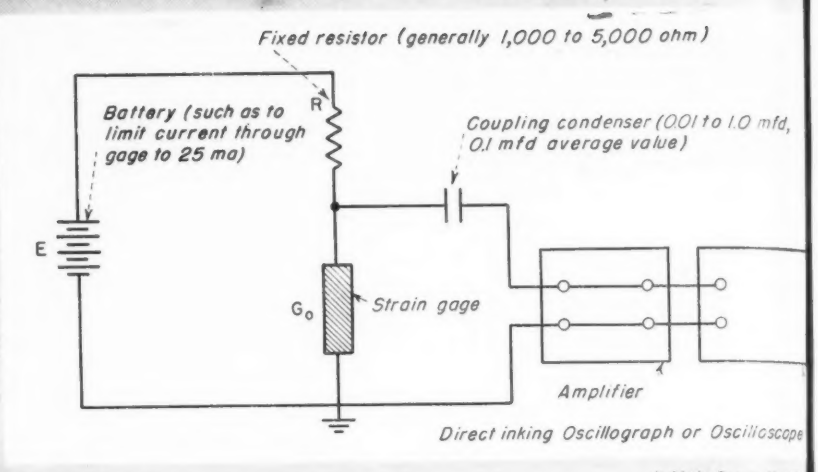
The instrument at the left plots strain data automatically. It records strain of one half-bridge on a continuously driven chart. Will make a record roughly less than 1 cycle per second. Costs $525 approximately. Next step to increase the versatility and speed of strain gage instrumentation is to add a switching unit so that up to 20 gages can be recorded by manually switching from one gage to the next.

E. Final Step Is to Use Automatic Recorder

This instrument looks like the recorder at left on the exterior. However it finds the balance of a gage or half-bridge, then automatically switches to the next gage. Will record up to 48 gages per minute. Approximately $2,000.

F. To Measure or Record Dynamic Strains

Simplest type of circuit that can be used is shown at right. Total cost is about $1,000. Limitations: (1) There is no means of calibration in terms of strain in the structure or of shift in the datum (zero) line on the oscilloscope screen or oscillograph record. (2) Handles only one gage and therefore this arrangement is not compensated for temperature effects.


Fixed resistor (generally 1,000 to 5,000 ohm)
Battery (such as to limit current through gage to 25 ma)
R
Coupling condenser (.001 to 1.0 mfd, 0.1 mfd average value)
E
G_0
Strain gage
Amplifier
Direct inking Oscillograph or Oscilloscope

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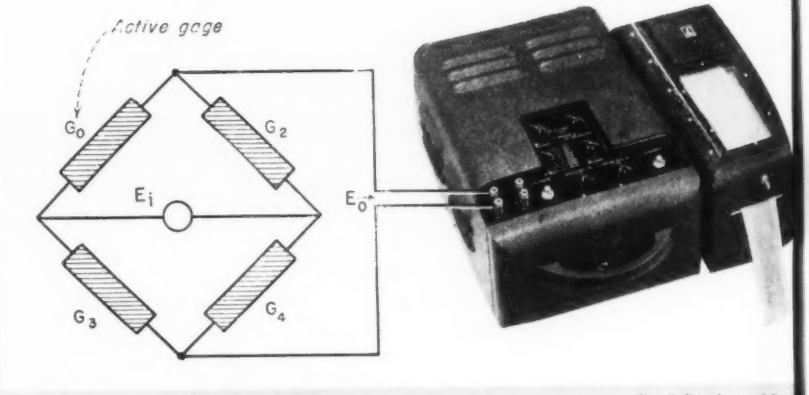
G. Dynamic Measurements With More Than One Gage

The Wheatstone network is used as shown. One gage can be active with temperature compensation or two gages can be used to double output as previously shown. About $1,000-$1,500 will cover the cost.

LIMITATIONS: (1) Only one gage or one half-bridge is recorded. (2) Lower practical limit of strain frequency is usually 5 cps approximately. Upper limit of strain frequency depends upon the particular oscillograph. (100 cps is average.)

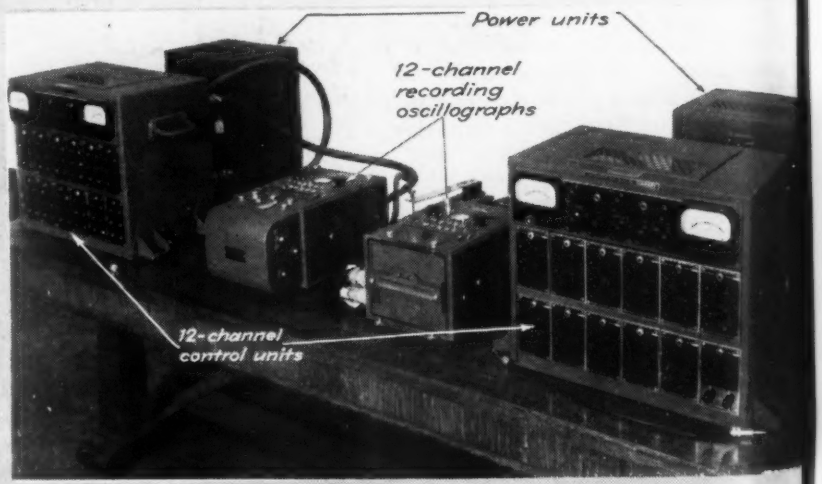


Brush Development Co.

H. Recording Dynamic Strains in Up to 24 Channels

Made in many variations, this equipment can be as elaborate as required. In the typical setup shown, two 12-channel recording oscillographs ($4,700 each) are fed by 12 channel control units ($3,500 each). Power supply units ($2,400 each) are shown behind control units.

Such an arrangement can be used to study simultaneously many points in a complex structure, as the machine is put through a service cycle.



Baldwin Locomotive

REFERENCES: For a good, but no longer up-to-date bibliography, refer to Bulletin 179, Baldwin Locomotive Works. "Resistance Wire Strain Gage Applications and Circuits" by Van Leeuwen and Gunning, PRODUCT ENGINEERING, July 1945, will guide the beginner. "Resistance Wire Strain Gage Equipment for Static and Dynamic Testing," same authors, PRODUCT ENGINEERING, Sept. 1945, describes applications and limitations of such instruments, and a precise method of calibration. Other articles on electric strain gage analysis will appear in PRODUCT ENGINEERING.

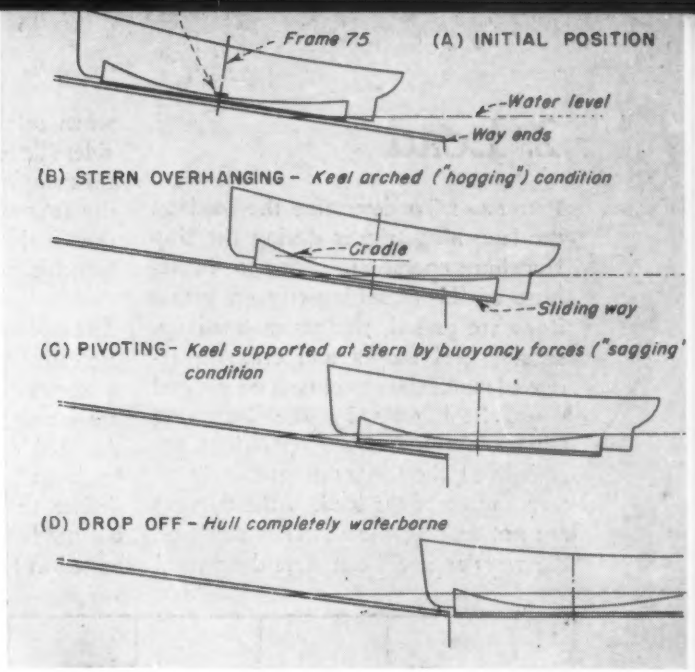
TYPICAL ELECTRIC STRAIN GAGE STUDIES...and what they revealed

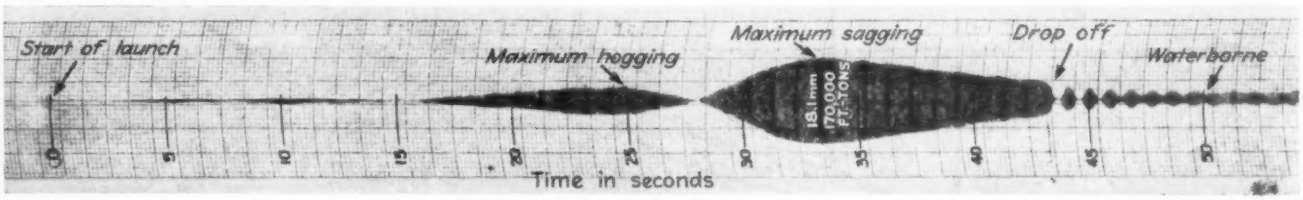
1. Stress

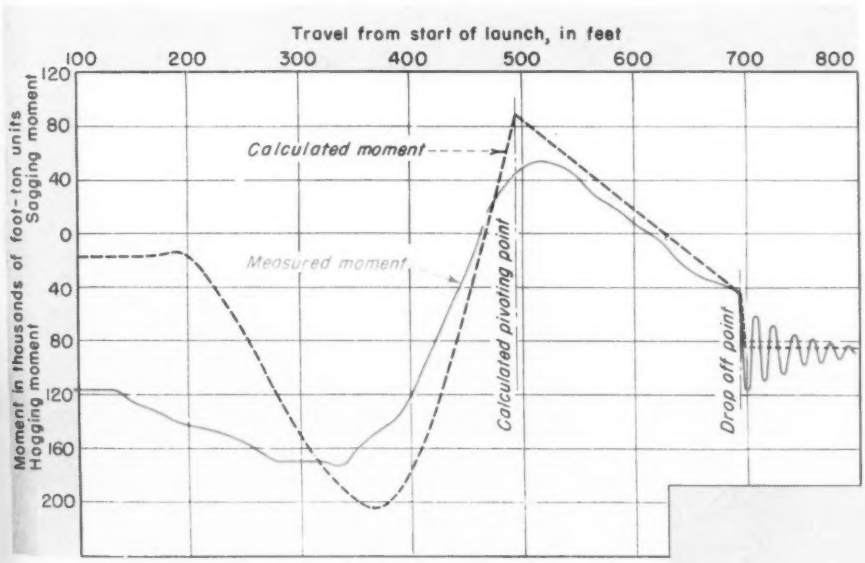
PROBLEM: To determine stress at various points in a ship's hull during launching, in particular, the stress in the keel, approximately amidship. During the launch, a hull undergoes several reversals of stress, as shown at the right.

EQUIPMENT: SR-4 gages were placed on the keel at several frames. Mechanical scratch gages were placed adjacent to check accuracy of the methods. Results from the latter are discussed in the section on mechanical strain gages.

TEST RESULTS: Shown by the oscillograph record below.


Frame 75
(A) INITIAL POSITION
Water level
Way ends
(B) STERN OVERHANGING - Keel arched ("hogging") condition
Cradle
Sliding way
(C) PIVOTING - Keel supported at stern by buoyancy forces ("sagging" condition
(D) DROP OFF - Hull completely waterborne



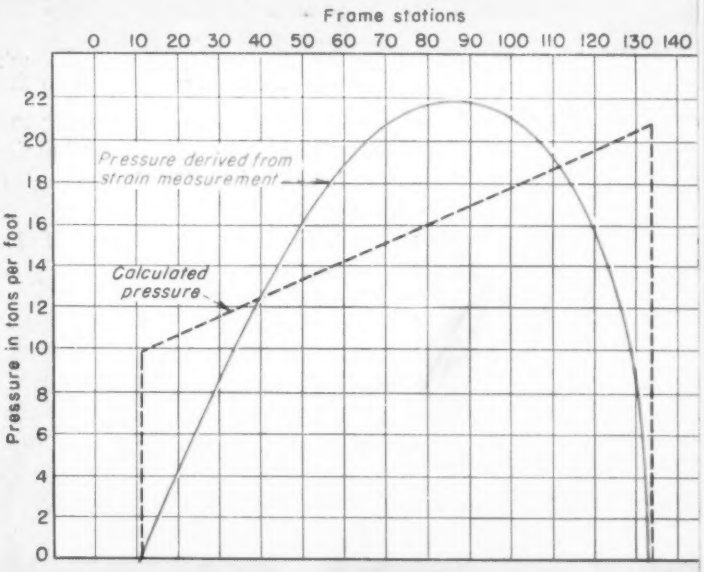


This data was plotted against the calculated moment values, giving the chart at left. Correspondence between calculated and measured values is quite good except at the start of the launch. Discrepancy of 5,000 ft-tons suggested that there was greater pressure near the middle of the ship than had been assumed for the initial launch position.

These results illustrate the value of making a preliminary mathematical analysis. Errors in theory or experimental technique are more likely to be detected.

An investigation was made to verify the distribution of pressure along the ways, which had been assumed to be trapezoidal. Curves of way pressure are given at right. The parabolic curve was obtained by making strain gage readings at various stations along the keel. The stress values causing these strains were then interpreted into pressure on the hull as ship rested on the ways prior to the launch. The trapezoidal pressure distribution, based solely on calculation, is incorrect. Thus, one result of this stress analysis study was to correct a long-standing error in theory. Equipment cost would be $2,000 at today's prices.

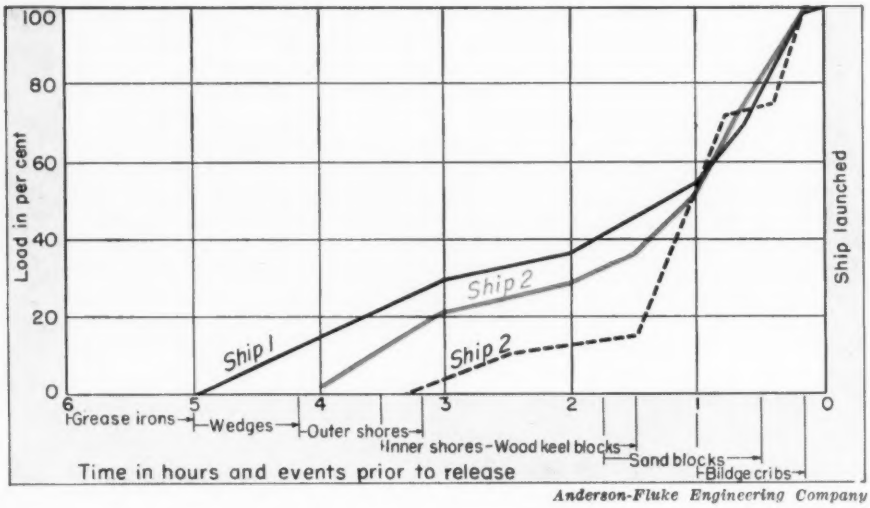
Illustrations adapted from "Two Aspects of the Dynamic Launching Problem," Trans. NE Coast Inst Engineers and Shipbuilders.



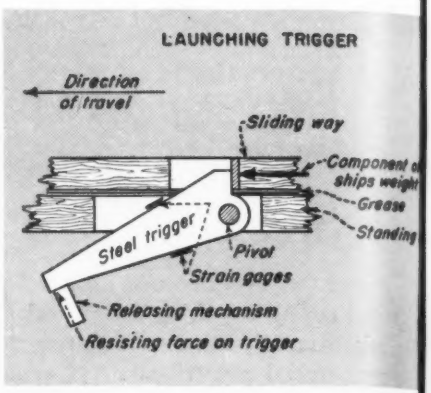
2. Load

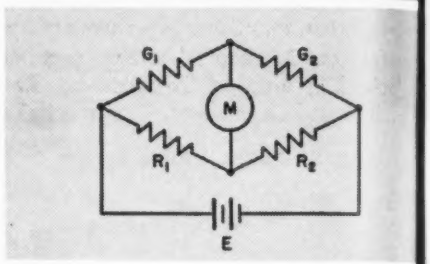
PROBLEM: To determine the load on the launching trigger during the ship launching operation. Prior to the release of the launching trigger, grease irons are pulled, wedges rammed up, shores, keel blocks and cribbing removed; until the vessel rests on greased ways, held only by the launching trigger. As the above operations are completed, the trigger progressively assumes more of the load. If the triggers are not loaded, the vessel is stuck on the ways and will not start downward when released. This may cause considerable expense, as well as embarrassment. SR-4 gages were used in the following arrangement to indicate the load on the trigger during the launching operation.

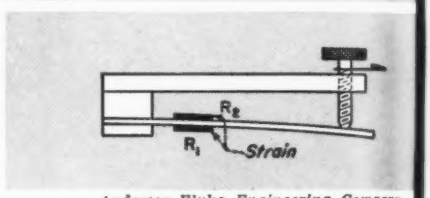
ARRANGEMENT: Strains in the trigger are calibrated in terms of load through a compensator circuit. Four gages are arranged as a Wheatstone bridge. As load on the trigger increases, the knob on the compensator is turned to deflect the beam until the bridge is balanced. Beam deflection is calibrated in terms of load on the trigger.



Anderson-Fluke Engineering Company







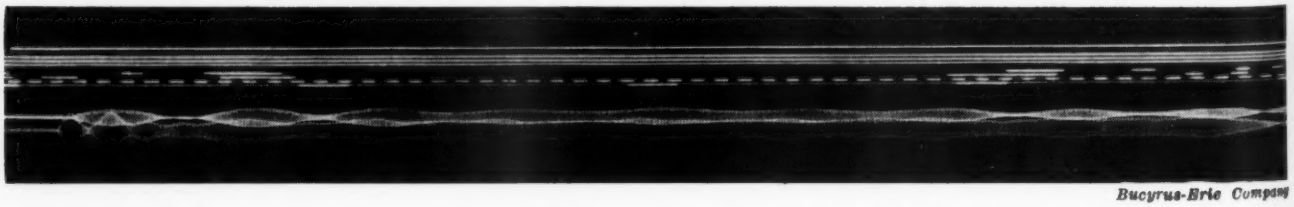
Anderson-Fluke Engineering Company

RESULTS: The strain gages effectively showed the increased stress (load) as the launching operation progressed. Data from three launchings are given.

3. Bending and Torque under Rotation Reversal

PROBLEM: To determine the amount of side bending in the boom and torque in the vertical swing shaft of a power shovel while "plugging." Plugging refers to the reversing the direction of horizontal traverse or swing by engaging the opposite clutch.

EQUIPMENT: Shown at the bottom of p 133.



Bucyrus-Erie Company

TEST RECORD:

Top timing line: White mark indicates that swing clutch for swinging left is engaged. Contactor was attached to the swing lever and mark comes when the lever is pulled, which is somewhat before clutch is in toggle.

Fourth and third timing lines from bottom: From beginning of one mark to beginning of next represents a 2.5 deg swing angle. Machine is swinging to right. After clutch is engaged, distance between marks increases because swing speed decreases. Speed goes through zero near middle of the record, then machine is accelerated in swinging to the left.

Second timing line from bottom: From beginning of one mark to next represents 1/6 rev of transmission shaft. Speed of shaft, hence engine speed, is essentially uniform.

Bottom timing mark: From beginning of one mark to beginning of next represents one second.

Upper strain gage record: Width of the band represents side bending of the boom. Lower strain gage record: Width of band represents torque in the vertical swing shaft.

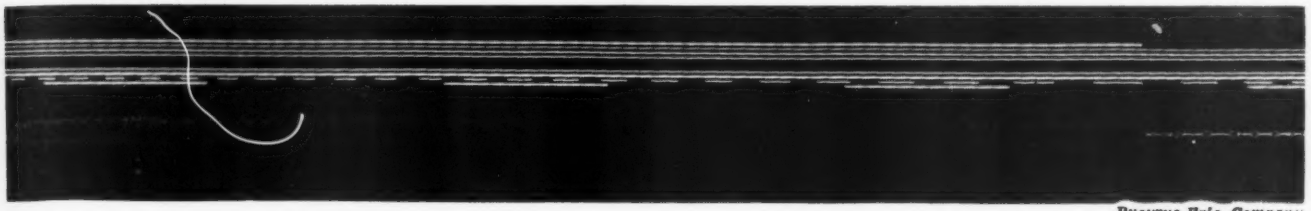
TEST RESULTS: There is a violent torque impact on the vertical swing shaft as the reversing clutch is engaged. Neither first nor subsequent peaks of rapid vibration are reflected in side bending of the boom. However, slower variations of swing shaft torque and side bending of boom are related.

4. Torque Fluctuation

PROBLEM: To compare the torque fluctuations in a transmission shaft as caused by 2-cycle and 4-cycle, 6-cylinder Diesel engines.

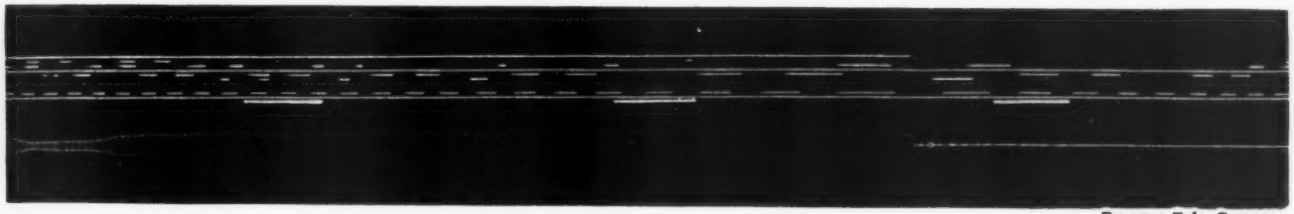
Equipment: Circuits and equipment used in these tests were homemade before any complete set was on the market. It is still more flexible, but costlier, bulkier, and more clumsy than commercial sets. Arrangement is sketched below.

TEST RECORDS: On each oscillograph record shown below the top timing mark is a white line indicating torque being applied by using the propelling clutch as a brake; the bottom timing line represents 1 sec from the beginning of one mark to the beginning of the next.



Bucyrus-Erie Company

Four Cycle Engine—Second timing line from the bottom represents 1/6 rev of the transmission shaft between beginnings of marks, which equals 0.886 engine revolutions. Strain gage record: Width of band indicates amount of torque in the transmission shaft. Torque fluctuates in synchronism with firing strokes of engine in most speed ranges; particularly severe in speed range from 400 to 360 rpm. No load speed is 900 rev per minute.



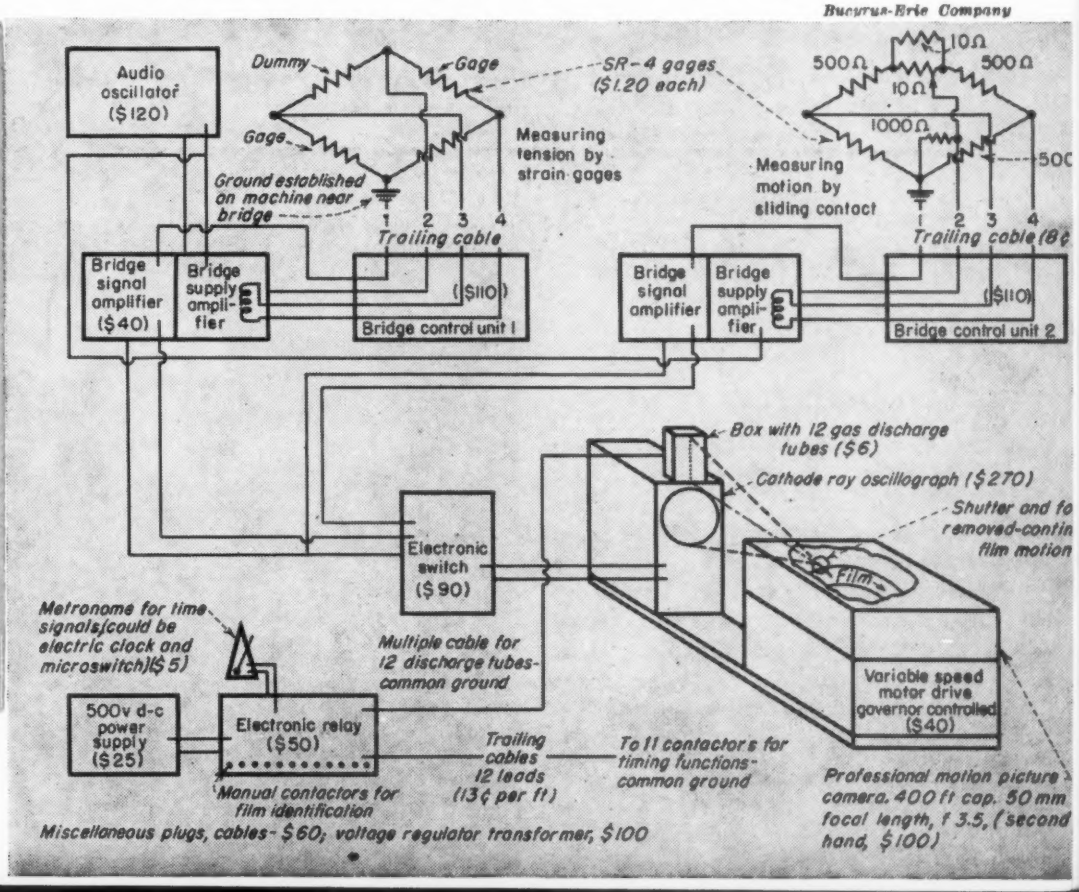
Bucyrus-Erie Company

Two Cycle Engine—Third timing line from bottom represents 1/6 rev of the transmission shaft from beginning of one mark to beginning of next; equivalent to 1.382 engine revolutions. Strain gage record: Width of band indicates amount of torque in the transmission shaft. Torque fluctuates in synchronism with firing strokes of engine from 350 to 180 rpm. No load speed is 1,400 rpm. Both engines pick up rapidly when the load is removed.

TEST RESULTS: Comparison and measurement of the strain gage records show that the 2-cycle engine produces less than one-tenth the torque fluctuation in the transmission shaft. Maximum torque is ±56 percent of average torque for the 4-cycle engine. Maximum torque produced in the 2-cycle engine is only ±5 percent of average torque.

Bucyrus-Erie Company

COST of assembling this outfit is given on the sketch in estimated current prices. Two gage bridge circuits are shown. Lefthand circuit is the temperature compensated arrangement for measuring tension. The righthand circuit is used to measure motion by sliding contact. A complete description appears in "Recording Unit for Strain and Timing Functions" by J. H. Meier, *Electronics*, April, 1943.



Mechanical Strain Gages

Mechanical strain gages often are the best, sometimes the only, means of measuring strain for certain applications. Although electric strain gages have replaced them in many stress studies, there are mechanical extensometers that make special measurements beyond the capabilities of any other technique.

PRINCIPLE

In general, mechanical gages indicate strain through mechanical lever magnification of the displacement between two knife edges clamped to the surface under test. A few gages use optical, photoelectric or electrical systems to magnify the strain reading.

ADVANTAGES

1. Useful for simple, short-duration static measurements where remote readings are not required.
2. Low cost.
3. Do not have to be replaced after use because they are not destroyed by removal from the structure.
4. Need not be calibrated as frequently as wire gages.
5. Some extensometers are usable at temperatures beyond the range of other kinds of strain gages.

LIMITATIONS

1. Not many gages can be used on a structure because they are difficult to read simultaneously. While this is sometimes a drawback, it often is an advantage because it forces the experimenter to take fewer, but more carefully planned, readings.
2. Most gages are not useful for dynamic studies and have too much inertia for impact loads.
3. Mounted on rotating, reciprocating or vibrating parts, the weight and bulk of the mechanical gage may change the balance or natural frequency of the member.
4. Mechanical gages are sometimes difficult to clamp securely to test surface.

REFERENCES

For a listing of gages with range and accuracy data, and references on individual gages, see "Types of Strain Measuring Devices and Their Range of Utility," Karl F. Smith, PRODUCT ENGINEERING, Jan. 1947, 107-110. "Recording Stress Level Gage," R. C. Walker and J. H. Meier, PRODUCT ENGINEERING, Jan. 1948, describes an ingenious mechanical-electrical gage.

TYPES

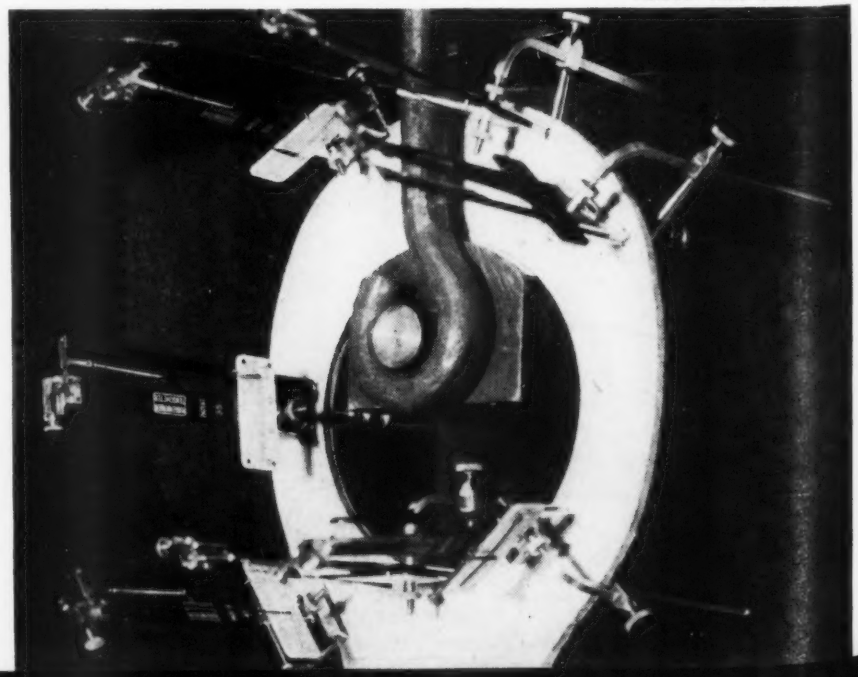
Of the dozens of mechanical extensometers made, only a few are described here to illustrate typical construction principles and stress analysis applications.

Richle Testing Machines

2. Dial Type Extensometer

This gage is typical of those principally used for yield point determinations. Movement within the 8 in. gage length is indicated on the dial. Smallest marking represents 0.000025 in. per inch. Cost: $30-$110 in various makes and gage lengths.

Baldwin Locomotive Works



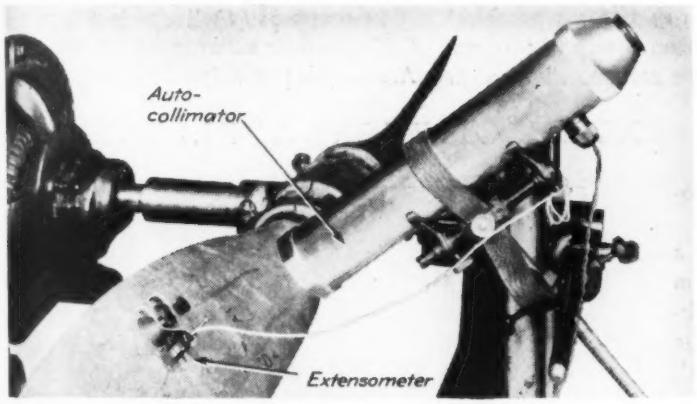
1. Huggenberger Tensometer

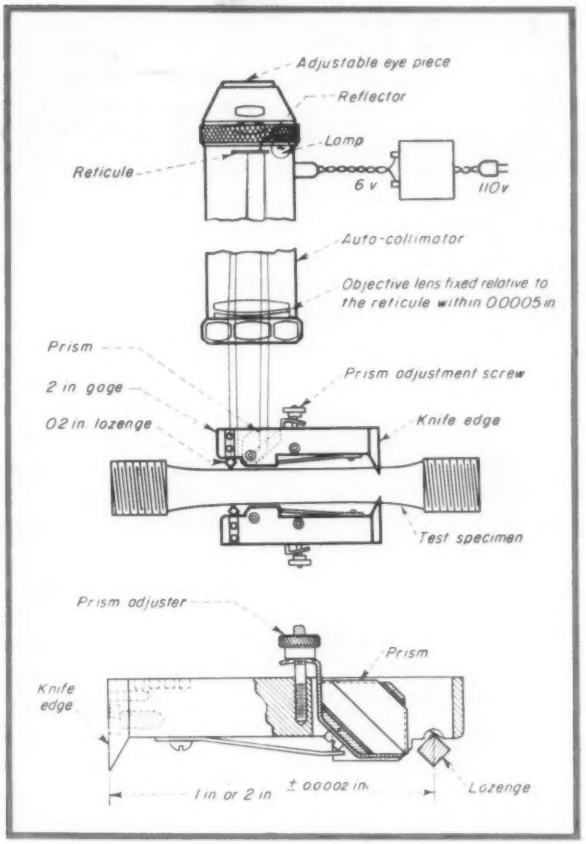
Used for studies on machine components and structures because a wide variety of clamping devices enables application to many surfaces. Strain indication is multiplied by the large mechanical leverage in the instrument. This standard instrument has a range of ±0.004 in. with indicating sensitivity of about 0.000008 inches. Cost: $90-$200, less attaching devices.

3. Tuckerman Optical Strain Gage

Useful for measurement of tension and compression strains as small as 0.000002 inches. Has been used on structural members such as airplane frames, panels, box beams, cylinders; also on riveted, welded and rolled joints. Strain occurring is manifested by a rocking of the mirrored lozenge. The degree of rocking is measured by displacement of the reticule image in the auto-collimator. The optical system allows the gage to be used on hot, cold, stationary, and vibrating members.

Advantages of this extensometer are its accuracy, (0.1 percent), its sensitivity (one half-millionth of an inch), operating range of temperatures, and variety of usable strain conditions. Cost: Under $1,000, depending on components selected.





American Instrument Company

4. Photoelectric Extensometer

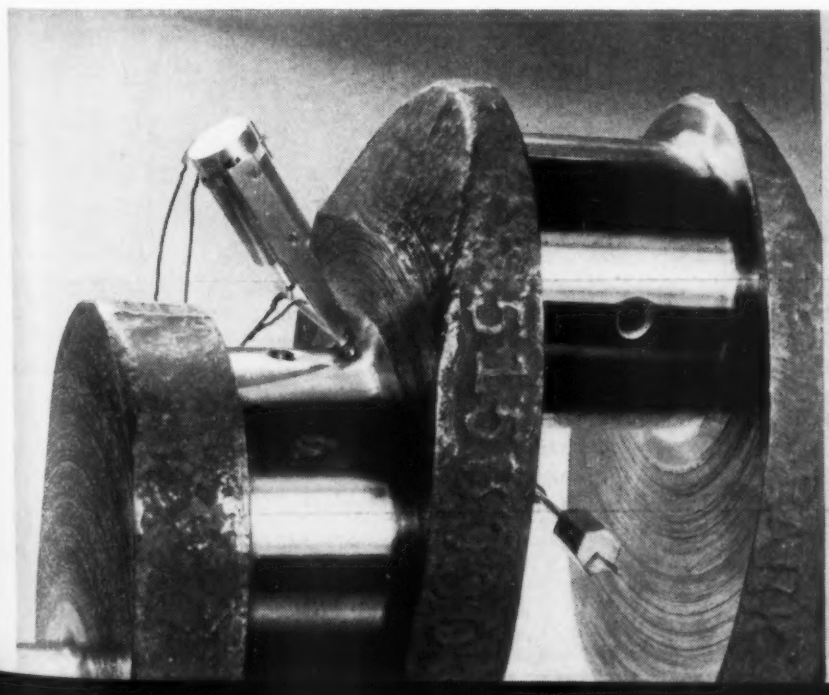
Developed by General Motors Research Division for making extremely short gage length strain measurements in areas of high stress concentrations. Strains measured are amplified mechanically and photoelectrically, 30,000 to 1. Strains as small as two-millionths of an in. per in. are indicated on the microammeter to within ±2 percent. This extensometer may be considered supplementary to the brittle coating and wire strain gage techniques in that the photoelectric extensometer is used to explore more thoroughly the critical areas.

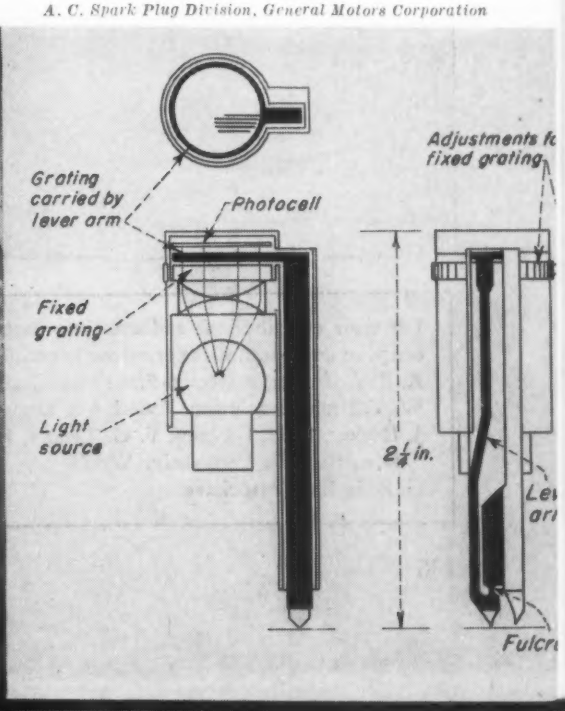
The illustration shows the gage mounted to measure strain in a crankshaft main bearing fillet. This usually requires a number of separate measurements at various angles at each point to insure that maximum strain has been measured.

Operating principle is based on varying the amount of light falling on a photoelectric cell proportionally to the amount of strain. As the surface strains, the lever arm carrying a grating, pivots about a fulcrum and changes the amount of light reaching the photoelectric cell. Gage unit weighs about ½ ounce, and gage lengths as short as 1/16 in. are available.

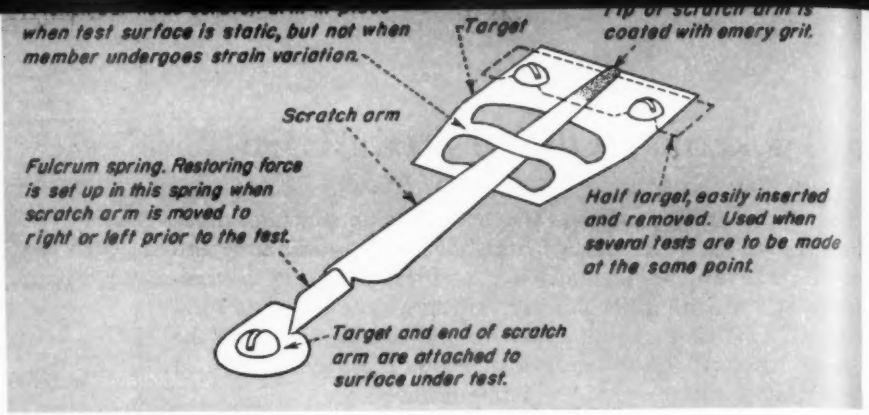
Advantages: The short gage length facilitates examination of small, critical areas. Limitations: Successful use of the gage requires considerable skill and care. Cost: Just under $1,000, including electrical equipment.

A. C. Spark Plug Division, General Motors Corporation





5. Scratch Gage


when test surface is static, but not when member undergoes strain variation.
Target
Tip of scratch arm is coated with emery grit.
Scratch arm
Fulcrum spring. Restoring force is set up in this spring when scratch arm is moved to right or left prior to the test.
Half target, easily inserted and removed. Used when several tests are to be made at the same point.
Target and end of scratch arm are attached to surface under test.

Baldwin Locomotive Works

Lightest, self-contained recording strain gage known is the DeForest scratch gage. A springloaded arm carries an emery coated point in friction contact with a small chrome-plated target. Both are screwed or soldered to the surface of the part to be tested. The gage is "cocked" by shoving the arm to one side or the other, where it is held by friction. As strain displaces the target relative to the arm, the friction grip is broken and the spring moves toward the center of the plate, scratching a trace. Results are interpreted by measuring displacement from the base line. The horizontal component of movement has no significance other than to indicate the sequence of events.

Advantages: (1) Gives a graphical record of strain on a structure where contact cannot be maintained through trailing wires. (2) Cost: About $25 for 10 arms and 30 targets. (3) Weighs less than 2 grams.

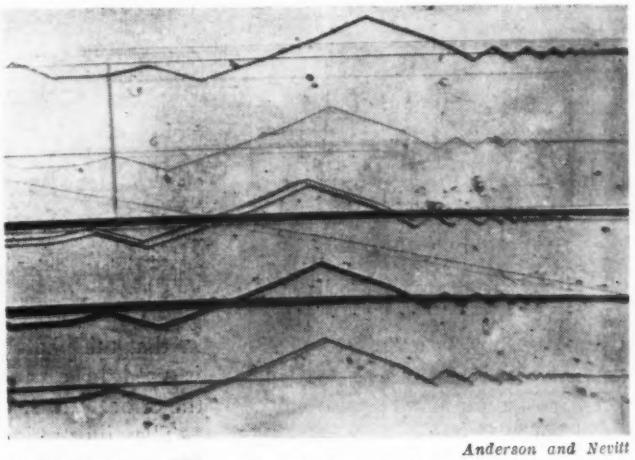
Limitations: (1) Range is 0.0001 to 0.050 in. over a 2 in. gage length. (2) Accuracy is probably off ± 10 percent.

EXAMPLE OF MECHANICAL EXTENSOMETER APPLICATION

Because it is one of the simplest yet least used extensometers, a scratch gage study is described here.

Problem: To determine stress at a point amidship in a ship's keel during launching. This is the same problem described in the section under Electric Strain Gages, Problem 1. The scratch gages were mounted adjacent to the SR-4 gages so that the results would be almost identical, and correspondence could be checked.

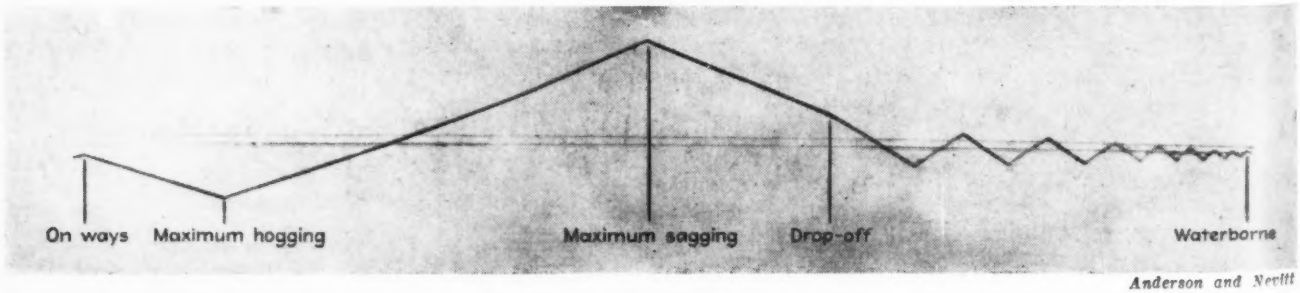
Test Records: Photograph of the target from a scratch gage on the keel is reproduced to show the appearance. All scratches were made at the same time, each scratch being made by a different emery grit particle. The best individual trace is selected for study and measurement. Strain is determined by measuring the actual displacement from the base line, with regard for enlargement in the photograph. Note the correspondence of selected trace below with the oscillograph record on p 131. The correspondence of scratch gage results is fairly close to that of the electric gage and definitely superior to calculation.



Anderson and Nevitt

Table I—Bending Moments at Frame 75, in Foot-Tons

Condition	Calculated	SR-4 Gages	Scratch Gages
On ways	−17,500	−112,800	−103,000
Maximum hogging	−204,700	−169,000	−164,000
Maximum sagging	+88,000	+57,200	+61,000
Water borne	−84,600	−84,600	−84,600



Anderson and Nevitt

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Why You Cannot Get Ahead As Your Father Did —

THE UNITED STATES is being forced toward socialism by a tax revolution of far-reaching consequences.

We have not yet felt fully the deadly impact of this revolution because inflation and the postwar boom have delayed its effect.

But from now on, more and more people will feel its bite. Already it is the dominant element in our economic life. Already it is the major factor in our chances of keeping our jobs and of getting ahead.

Here are some pertinent facts on this tax revolution:

1. The tax load that our nation can safely carry has long since passed the danger point.

Our capitalistic system is in real danger when taxes take more than 20 percent of our national income (or 20¢ out of every income dollar). Beyond that point there are not sufficient dollars left in private hands for capitalistic America to raise the capital required to keep its industry going. So we are right now being nudged further and further into socialism.

For today taxes take *twenty-five* percent of national income (or 25¢ out of every income dollar).

2. The tax revolution has undercut the incentives that help us to get ahead.

The group whose incomes range from $5000 up now turns over about one-half of its *total* income to federal, state, and local tax collectors. Before the war, this group gave the tax collectors one-third of its collective income.

In sharp contrast, the group of people with incomes under $5000 pays the tax collectors 20% of its income for direct and hidden (mostly hidden) taxes—against 18% before the war. This lower-bracket group needs immediate tax relief but I believe most sincerely that persons earning less than $5,000 have a very vital reason for also supporting tax relief in the much more heavily hit upper brackets.

As you get ahead, you expect your taxes to go up. Taxes should be levied, in principle, according to ability to pay. But today tax rates rise so sharply that they virtually destroy all incentives to get ahead, to save, and to invest in new and untried enterprises that open up new jobs. *The progressive tax idea now carried to punitive extremes has become a destructive tax revolution.*

Today the U.S., envied by all the world for the wealth it has won under capitalistic incentives, has cut its incentives below those offered by that state whose police methods strike terror into the hearts of all workers.

Soviet Russia rewards successful managers, writers, and scientists better relatively than we do under our present tax system.

A revolution that sweeps away incentives will quickly sweep away our free enterprise economy. The only substitute ever found for free incentives is the whip-and-lash compulsion of the police state. And no police state has ever been able to match the production of a free people with a free economy that gives adequate rewards to individual producers.

3. The tax revolution hits squarely the average American's chances of keeping a job and of getting ahead.

If you make less than $5000 a year you may well ask why you should worry about a tax revolution that seems directed at the comparatively small group, about 10% of American families, who make $5000 a year or more.

The answer, it seems to me, is that "risk capital," the money that makes new jobs when invested in growing companies or in new businesses, must come largely from the people making more than $5000 a year. The others usually cannot afford to take any risks with their savings.

It was the savings of this 10% group that made possible the huge growth in American industry and American jobs and our progress in raising American living standards in the years before 1930.

Now the government is taking so much from the 10% group in taxes that they cannot afford to risk any savings they manage to accumulate. Most of their savings now go to insurance companies and savings banks which are barred by law from making risky investments or investments even in seasoned common stocks.

The flow of risk-capital from this 10% group can only be renewed by reducing their taxes. The result will benefit everyone over the difficult years to come by providing more and steadier employment for all.

The cost of the presently proposed reduction, *less than 1% of the national income,* can well come out of current revenue surplus. It will be repaid many-fold by the new enterprises it will stimulate.

4. Jobs will be lost if risk-capital does not increase.

Unless the flow of risk-capital into business *can be doubled* and *trebled* in the next few years, business investment in job-making new plants and equipment will drop sharply. The McGraw-Hill survey of prospective capital expenditures, reported in the previous editorial in this series, made that quite clear.

When such a drop in business investment has come in the past, it has brought with it a general slump in business — and unemployment.

As we work through the enormous demand for goods of all kinds built up during the war years, and as the war-accumulated savings of businesses and individuals are spent, it will be harder and harder to keep production and employment at today's high levels.

Then—at the very time that we shall need all our drive to maintain prosperity—we shall be hit by the full impact of the tax revolution.

5. Compounding these troubles is a tax system as out-of-date as an oxcart.

Twenty years ago, when taxes took only twelve cents out of the national income dollar, our rattle-trap tax system was little more than a nuisance. Today, when it takes twice as big a bite, its double-taxing of the earnings of investors, its discriminatory excises, and the overlapping of federal, state, and local levies are a fatal handicap. A new system, a fair system, a rewarding system, is a necessity if American initiative and enterprise are to have a fair chance.

What Congress does now about federal taxes will bear crucially on our ability to sustain prosperity.

By demanding economy in government and by re-designing the tax system to stimulate initiative and risk-taking, Congress can multiply many times our chances of maintaining full employment and of raising living standards.

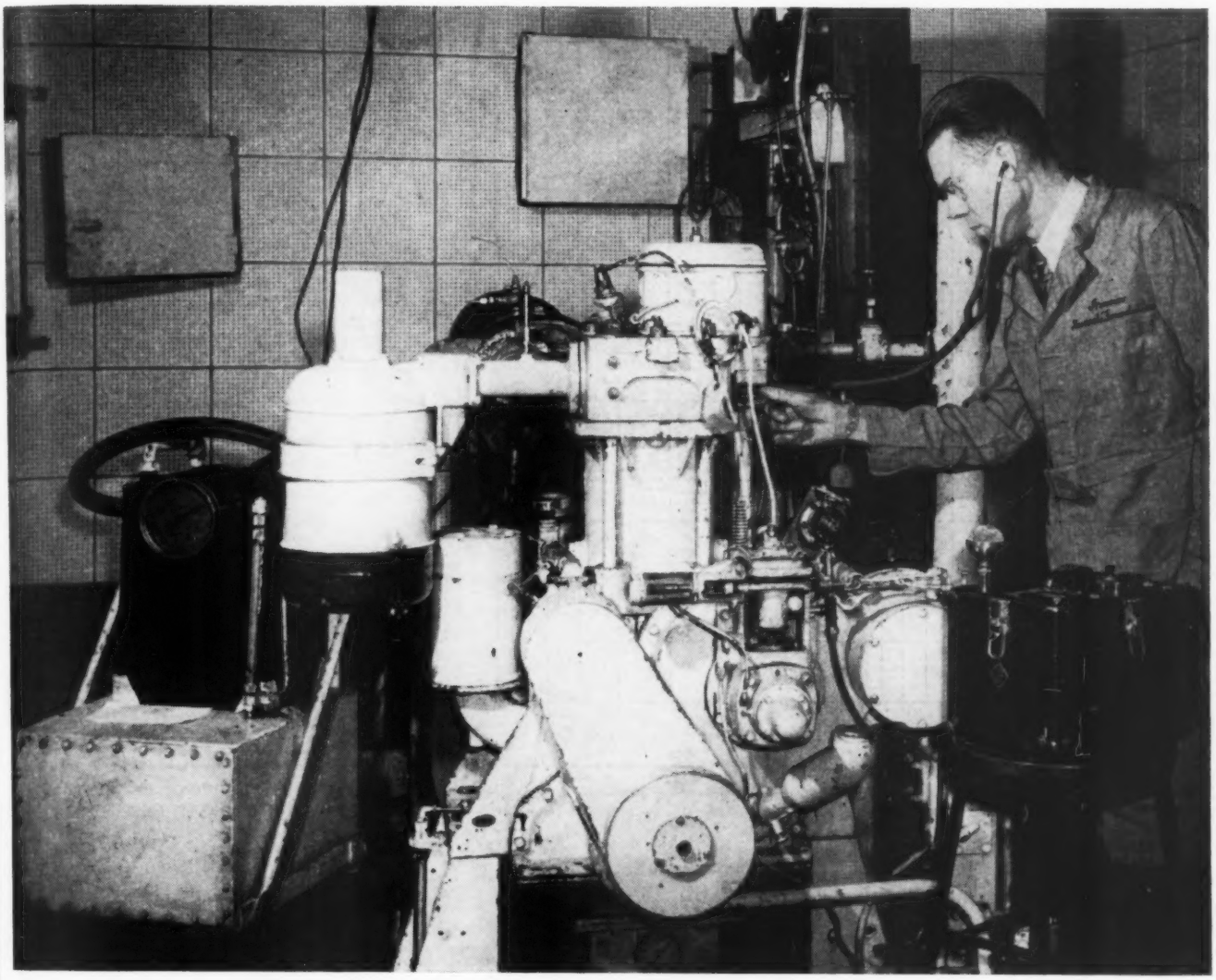
By allowing people to save more and by renewing the incentive to risk capital in new enterprises, Congress can actually insure a bigger tax return in the years ahead. More business will result — and pay more taxes.

That is the only way that a free people with a free economy can carry the tax load.

That is the best way that our government can improve our chances of keeping our jobs and of getting ahead. I suggest that you discuss these vital matters with your chosen representatives in Congress, in your state government, in your local community.

President, McGraw-Hill Publishing Company, Inc.

THIS IS THE 66TH OF THE SERIES



USING A STETHOSCOPE to find a source of noise. This is an effective technique for many problems, although it does not always locate the exact source. View is taken in the sound booth in the engine laboratory, Armour Research Foundation.

Analyzing Machine Noise

Seven steps of a procedure for improving the acoustic performance of machinery.

HOWARD C. HARDY
Supervisor, Acoustics and Vibration Section
Armour Research Foundation of Illinois Institute of Technology

DEVELOPMENT of an acoustical laboratory and the training of an acoustical engineer can be justified only by substantial improvement in the product. To accomplish the results in an economic fashion, approximately this approach is recommended:

1. Find the sources of sound radiation.
2. Determine which of these are the most important. Isolate this source from the others, if possible.
3. For this sound source, identify the source of sound energy and try to reduce it.
4. Find the coupling between the source of sound energy and the radiating source and determine whether decoupling is possible.
5. Try to increase the mechanical impedance of all the moving parts.
6. Study the problem of radiation and how to diminish it.
7. Incorporate the accomplishments into a new design and proceed to the next most important noise source.

Separation of the problem into its various elements is recommended, rather than trying over-all treatments. In nearly every one of the analytical steps, an examination of the noise spectrum will give the most important clue to solving the problem. The spectrum analysis can be a sort of X-ray for finding out what is not directly apparent. Sound spectra for some typical devices are shown in Fig. 1. Steps in solution of noise problems are shown by examples that follow.

FIND THE SOURCE OF SOUND

By use of the stethoscope as shown in the lead picture, or more elaborate instruments, the general area from

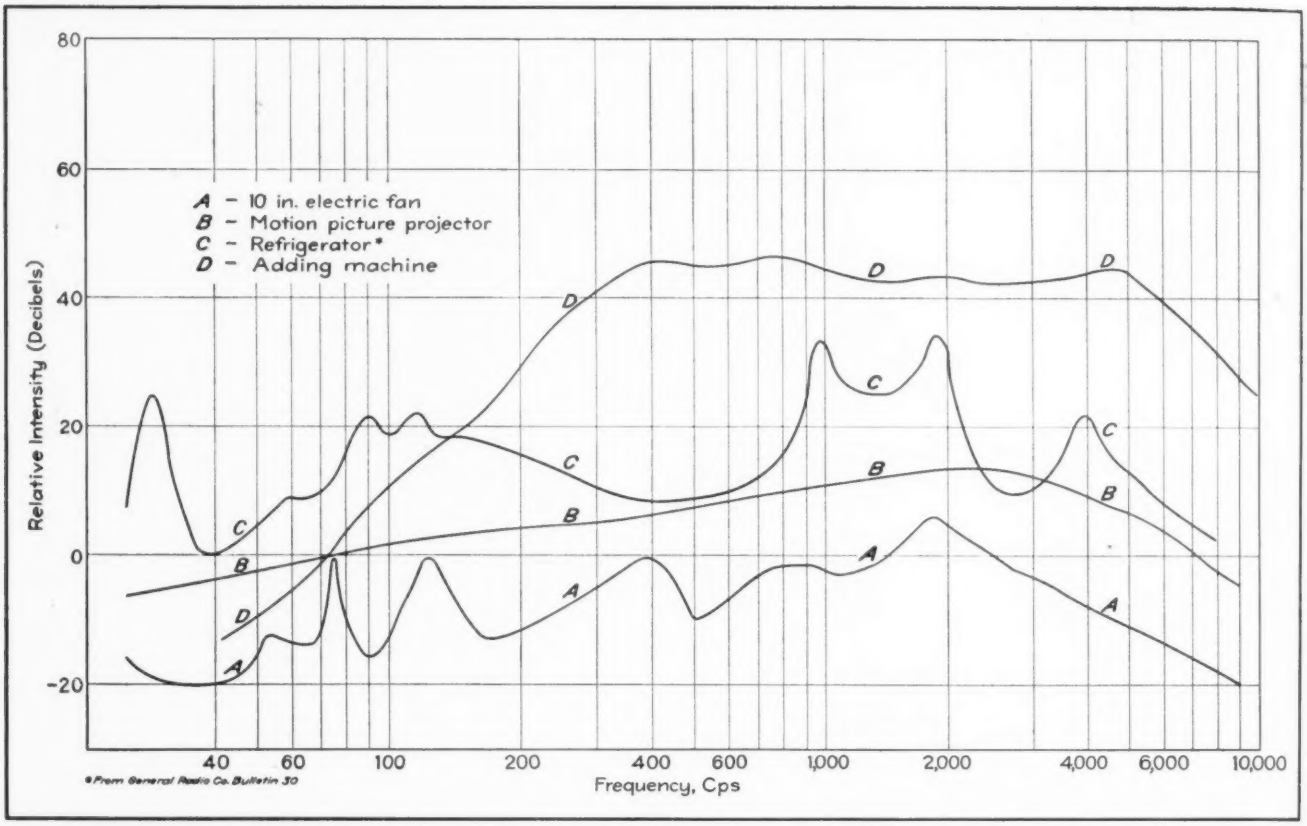


Fig. 1—Sound spectra of four mechanisms: projector, fan, refrigerator and adding machine. Energy source of the broad spectrum of the motion picture projector is particularly difficult to identify because there are no peaks around any given frequency.

which the sound comes usually can be easily determined. But this does not always identify the actual source of sound. A V-belt squeak provides an interesting example.

The sound was found to come from a point near the entrance and emergence of the belt from a small pulley. The actual source of sound radiation, however, was still unknown. The spectrum was taken, and a resonant peak was found at a frequency corresponding to the characteristic pitch of the sound. Nothing from the belt resonated at this frequency. One of the natural resonate frequencies of the pulley was near, but not exactly at, the resonant pitch. Moreover, the same squeak occurred with different pulleys having different natural frequencies. Eventually, the squeak frequency was found to correspond to the natural frequency of the air column under the V-belt, between it and the pulley. The air column acted similarly to an organ pipe or whistle in amplifying the sound at one particular part of the spectrum. Lengthening the air column reduced the pitch, shortening it raised the pitch. Once the radiating source was known, treatment followed as a matter of course.

This illustrates the method of attack. The spectrum of the sound provides the necessary information. The next step is to find something that changes the spectrum. This will usually lead to more important results than trying to find something that changes the loudness of the noise. The causes of loudness usually are not obvious, and are extremely difficult to measure. But whatever operation changes the pitch of the sound should indicate the source.

Determine the Most Important Source

When more than one source of sound is present, which shall be studied first? Analysis of the spectra and identification of the radiation sources will generally indicate the relative intensity. The most annoying source can be judged by listening. For instance, the refrigerator, whose spectrum is shown in Fig. 1, has several characteristic frequencies. Although the highest points are not much different in intensity, the high frequencies are more annoying and should be attacked first.

Suppose that these frequencies have been identified with the piping and panel vibration. The next step is to separate them so that each can be studied in turn. This can be done by removing the panels, which obviously leaves only the possibility of piping noise. The piping noise can then be excited by shaking or tapping.

Identify the Source of Sound Energy

The spectrum is often the best clue to the source of sound energy. A correlation between the spectrum and the frequencies found by stroboscopic examination will be important. Multiples of the driving frequencies, even submultiples, should be looked for. For instance, frequencies that are exact multiples of 60 cps can usually be attributed to hum for equipment using alternating current.

When the spectrum is extremely broad, as for the motion picture projector and the adding machine whose spectra are given in Fig. 1, there is usually no highly resonant radiating source. In these instances the source of sound is usually caused by multiple impact or rubbing surfaces. Then each moving source should be studied separately, insofar as possible, to find how much each contributes to the spectrum.

This work becomes painstaking, but will produce results if carried out thoroughly. For instance, three sources of about equal intensity but different spectra are found in the average motion picture projector. They are the fan, the motor, and the sprocket gear

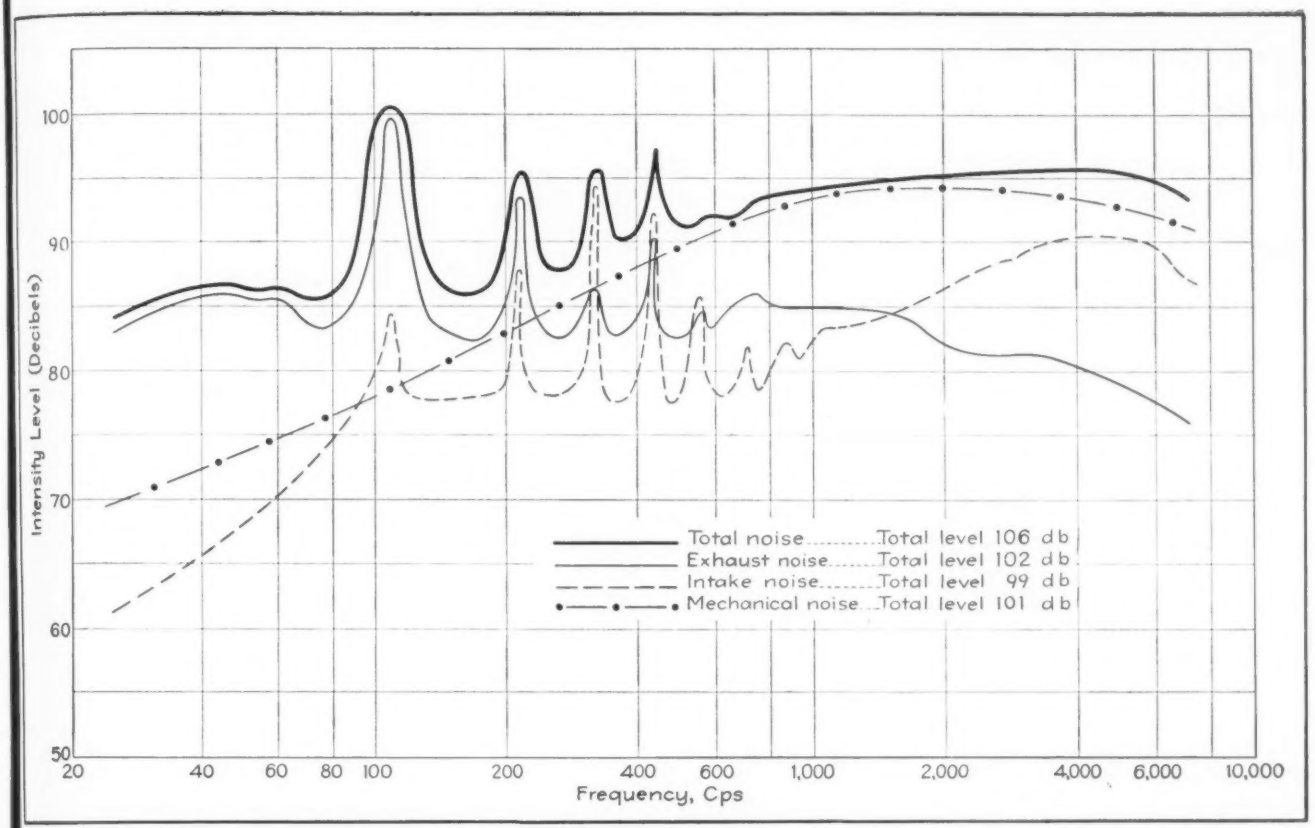


Fig. 2—Analysis of the noise of a hypothetical gasoline engine. The three main sources of noise, exhaust, intake, and mechanical, have much different spectra, although each has about the same total level. It is necessary to study each noise source separately.

train. Each must be studied separately.

Another example that illustrates the necessity of identifying the different sound sources is given in Fig. 2. This analysis of a hypothetical gasoline engine shows three main sources of noise: exhaust, intake, and mechanical. Each have different spectra, and must be studied separately.

Find the Coupling Between Source and Radiation

The coupling between the energy source and radiating source will usually be mechanical, although sound in an enclosure may transmit the energy to the walls of a container, and in electrical machinery there may be magnetic coupling. There are so many different combinations, each of which is so different, that it is difficult to draw general conclusions from a single case. Many of these problems can be aided by vibration isolation, which is a fundamental technique for acoustic improvement.

Most vibration isolators work on the principle of introducing something that has low stiffness, such as a spring, rubber, or felt, between the applied force and the support. In all such constructions the total mass being moved in combination with the stiffness of the isolator gives a resonant frequency. (See Equation 7, "Sources of Machine Noise," Product Engineering, Mar. 1948, p 87.) It should be remembered also that for such substances as rubber and felt, which have large mechanical hysteresis, the dynamical stiffness may be higher than the static stiffness. [For elaboration see Eisenhour and Tyzzer, *J. Franklin Institute,* 214 No. 6, p 691 (1932); also Tyzzer and Hardy, *Journal of the Acoustical Society of America,* Vol 19, No. 5, pp 872-878 (Sept. 1947).] Therefore, when the frequencies in the energy spectrum are near those of the mounting, the transmitted effect will be worse than with no isolator at all. It is important, therefore, that these parameters be known. Measurements of the effect of isolating materials can be made with a vibration meter.

As an example of an application of mechanical isolation, consider a problem of an air-conditioning system with a motor operating at 1,800 rpm, or 30 cps, and a fan being driven at 600 rpm, or a 10 cps frequency. These frequencies are too low to be annoying themselves, but the forces generated by their harmonics may excite higher resonant frequencies in the wall or ceiling to which they are connected.

Suppose that it is decided to provide vibration isolation, but that all the standard vibration isolators under this loading give a resonant frequency between 10 and 20 cycles per second. The best solution then would be a spring suspension of about 4 cps resonant frequency. The next best solution is to use a rubber isolator with about a 15 cps resonant frequency. This will amplify the vibration at 10 cps, but will cut the high harmonic components that excite the wall. Under these conditions the increased amplitude at 10 cps will be apparent to the eye and can be felt if the unit is touched. However, this may not be objectionable.

It is premised in the above discussion that the wall does not have a resonant frequency near 10 or 30 cycles per second: in other words, that the mechanical impedance of the wall is much greater than that of the mounting. Often this is not true. Then the only solution is to specify a proper type of support such as stronger wall brackets, or even a new wall. It is surprising how often a flimsy wall is the cause of noise and vibration, rather than poor acoustic design of the product.

Increase Mechanical Impedance

As previously discussed in "Sources of Machine Noise," Product Engineering, March 1948, pp 87-91, in-

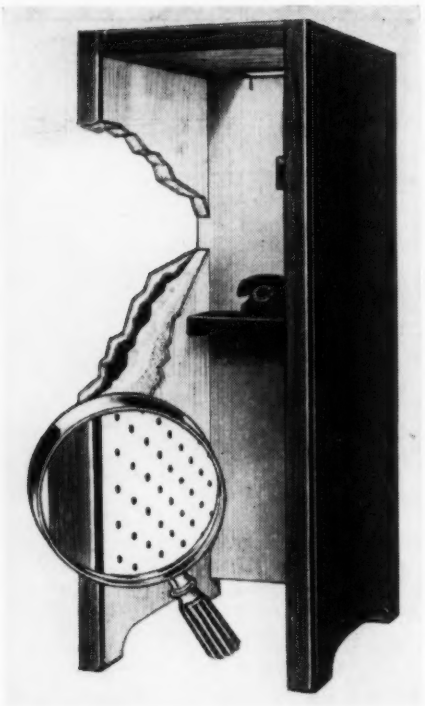


Fig. 3—Sound passes through small holes in the inner wall and is partly absorbed within the sound absorbent lining behind the wall. Partial enclosure decreases the radiation impedance. The combined treatment effectively reduces the apparent loudness.

creasing mechanical impedance can be accomplished by changing frictional damping, mass, or stiffness. An example is the rubber-bladed fan. Here the damping is greatly increased, and the lower stiffness has changed the natural frequencies to very low values, the mass remaining about the same.

Another example of effect of low mechanical impedance is the noisy punch press. Great variation in the sound output of various makes of punch presses has been noticed, even though the presses are being used on closely similar work. Invariably, the quieter presses have heavier anvils. Sometimes the presses are placed on floors that are too light, thereby giving large amplitude to the whole building. Unfortunately, the trend in recent years has been to reduce the mass of punch-press castings, which leads to poor results acoustically.

Reduce Sound Radiation

The best ways of reducing sound radiation are the following:

(a) Lower the frequency of the radiation.

(b) Reduce the size of the radiating surface.

(c) Remove baffles so that the sound becomes a dipole source.

(d) Enclose the object.

Method (a) only points out again the importance of lowering the frequency, which has other advantages, such as less annoyance, previously discussed. Many examples of reduced sound radiation through lowering the frequency of rotating machinery are well known throughout industry. The automobile muffler also accomplishes part of its function by reducing the frequency of sound radiated.

Possibilities of applying methods (b) and (c) will be apparent from a study of the particular product. The principles have already been discussed in some detail in "Sources of Machine Noise," Product Engineering, March 1948, p 87, and some examples are given there. Consider, in addition, the following example.

A motor is completely enclosed within panels and tightly coupled mechanically to one of the panel walls. The hum of the motor is quite pronounced because it is amplified by vibration of the panel. Reduction of the coupling is difficult because of the mechanical construction. Stiffening the panel, which increases the mechanical impedance, helps somewhat, but not enough reduction is obtained. Then the particular panel is reduced in size and made stiffer by a different shape of enclosure. Considerable improvement results. Finally, the desired reduction is obtained by putting holes and slots in the driven panel and the adjoining panels. This last step removes the baffle of the radiating source and essentially changes it from a simple radiator to a dipole source. Dust is kept from the enclosure by a cambric covering over these holes. Thus, by a combination of treatments, a major reduction in sound radiation is made.

Method (d) is a rather obvious, but usually a rather unsatisfactory way of reducing the sound, because it increases the size and weight and does not leave the parts readily accessible. It should be used usually as a last resort. Before discussing enclosures, however, it is necessary to distinguish between sound absorbing materials and those which reduce transmission of sound.

The word "absorption" is applied to the properties of a material which cause it to reduce reflection of sound. In this sense, an open window gives 100 percent absorption, although it has zero reduction in transmission. Most of the best sound absorbers make use of the friction of air flow around small fibers. Examples are felt, cane fiber, fiberglas, and rock wool. None of these are good for reduction of transmission at low frequencies unless ridiculously great thicknesses are used. The best reduction of transmission at low frequencies is accomplished by either massive structures or multiple walls, both of which are awkward.

The sound radiated from an object can be reduced in some cases by partial enclosures using sound absorbing material. An example of this is illustrated in Fig. 3, an open telephone booth. Partial enclosure reduces the radiating area, which decreases the radiation impedance; and the absorbing material absorbs some of the sound in the interior.

A precaution is needed with all enclosures. Many disappointing cases have happened where more noise was obtained with an enclosure than without one. The causes of this have been (1) the enclosed chamber forms a resonate cavity, (2) the sides of the enclosure were coupled to the interior vibration, and (3) the radiation was changed from a dipole to a simple radiator source.

An Error on Noise

Equation (1) in the article "Fundamentals of Noise," February 1948, p 131, should be corrected to read

$$I = \frac{p^2}{\rho c}$$

In the article, c was erroneously printed as the exponent of ρ.

* * * *

Because of whiteness, luster, and resistance to wear and corrosion, nickel has been used in worldwide coinage systems since the first pure nickel coins were struck in 1880. It has been estimated that 90,000,000 lb of nickel have been used in pure and cupro-nickel coins. Nickel offers obstacles to counterfeiters and is most valuable for this property.

* * * *

The first mechanical air pump is attributed to Otto von Guericke and was made in 1650. It was a common suction pump very similar to a piston water pump. The pump was a long narrow tube which was fitted with a plunger and two automatic leather valves. It was with a later design of this pump that Guericke exhausted the air from the "Magdeburg" hemispheres in his celebrated public demonstration. The hemispheres were placed together, evacuated and could not be separated by two teams of eight horses each.

Fig. 1—An experimental radio panel being metallized. This is a laboratory operation: a heavy duty metallizing gun and automatic handling equipment to pass the panels through the metal spray would be used for large scale production.

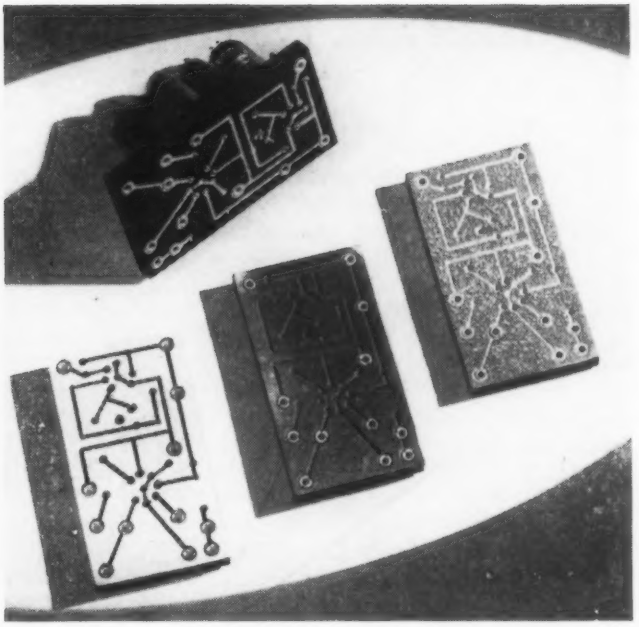


Fig. 2—Left is a panel with stencil applied. Eyelets were inserted prior to application of the tape stencil. Center panel has been sandblasted. Right panel has been metallized, stencil is still in place. Above is bottom view of the completed amplifier.

Metallized Circuits

New technique for mass production of electrical wiring—advantages and costs.

JOHN T. COLLIER
Spraywire Laboratories, Inc.

MASS PRODUCTION of electrical circuits by metallizing, or spraying the wiring, is a recently developed means for the elimination of hand wiring in many applications. Instead of improving the method of installing conventional wiring, this process replaces drawn wires with a different type of conductor, which lends itself to automatic mass production methods. These metallized circuits consist of strips of metal imbedded in grooves in a base dielectric material.

Briefly, this is the process. A stencil, prepared in exact conformity with the basic wiring design to be produced, is applied as a masking to a dielectric panel. Sandblasting the panel through the stencil forms grooves coinciding with the openings in the stencil. Still masked by the stencil, the panel is sprayed with metal, using standard metallizing techniques. In this step metal is sprayed through the stencil openings into the channels in the base material, forming the inlaid metal strips of the circuit.

A special masking tape has been developed for use as stencil material. This tape is lightly adhesive on the side applied to panels, and has a hard outer surface, able to withstand sandblasting and metallizing. Stencils made of this material can be die-cut in continuous strips, and are used only once. After use they can be collected for salvage of the metal deposited on their surfaces. When this type of stencil is used, it is advisable to allow a minimum separation of 1/16 inch between conductors.

Favorable results have been obtained in the experimental use of metal stencils faced with rubber coatings. These stencils are semipermanent. The rubber prevents metal deposits from building up on the stencils, and sandblasting cleans off any metal that adheres to the rubber coating. These stencils are used to best advantage in the production of small, complex panels.

In many applications it is possible to eliminate the use of stencils and sandblasting by molding relatively deep grooves in a plastic base material, and metallizing the entire panel. Metal deposited on the panel outside of the grooves does not bond strongly with the smooth plastic surface and is easily stripped off, fracturing at the edges of the grooves so as to leave the conductors intact. If the grooves are sufficiently deep, little or no metal will be deposited on their vertical walls. When sandblasting is not used, the sprayed conductors do not effect as strong a bond with the base material. However, molded grooves are roughened insofar as possible, and adhesion of conductors to the base material can be improved mechanically by applying an over-all adhesive insulator to the completed panel.

Metal eyelets, inserted in the panel prior to sandblasting, form terminals for the connection of component lead wires to the sprayed elements of the circuit. These eyelets are so positioned as to be metallized into permanent contact with the conductive strips when the latter are sprayed in. Eyelets are also used as connections between sprayed conductors on the opposite sides of the same panel. Steps in the process are illustrated in Fig. 2 by three stages in the wiring of a small amplifier.

The technique of spraying is of particular importance in that it affects the porosity and therefore the resistance of the sprayed conductors. The method of spraying must be ad-

justed to the type of equipment used, the metal being sprayed, and the material being used for a panel. When the Metco 2E metallizing gun is used with copper, plastic panels are sprayed at a distance of six inches from the gun. This will provide for deposits of the proper porosity. Passes at the rate of one foot per second will insure that the plastic is not damaged by burning at this close range. Each pass deposits an average of 0.0035 in. of metal; two passes, or movement of the panel before two guns in sequence, will provide the thickness of 0.007 in., which is suitable for most applications. Sprayed copper has a hardness of F78 to F79, and its specific gravity is 7.535. The resistance of properly sprayed copper conductors will not exceed the resistance of copper wire by more than ten percent.

The practical minimum width for a conductor is 1/16 in., and a width of $\frac{1}{8}$ in. or more is preferable from the mechanical standpoint. Stencil openings of less than 1/16 in. retard the uniform deposit of sprayed metal in the channels of the base material. Above these minima, sprayed conductors can be made as wide as required by the currents they are to carry.

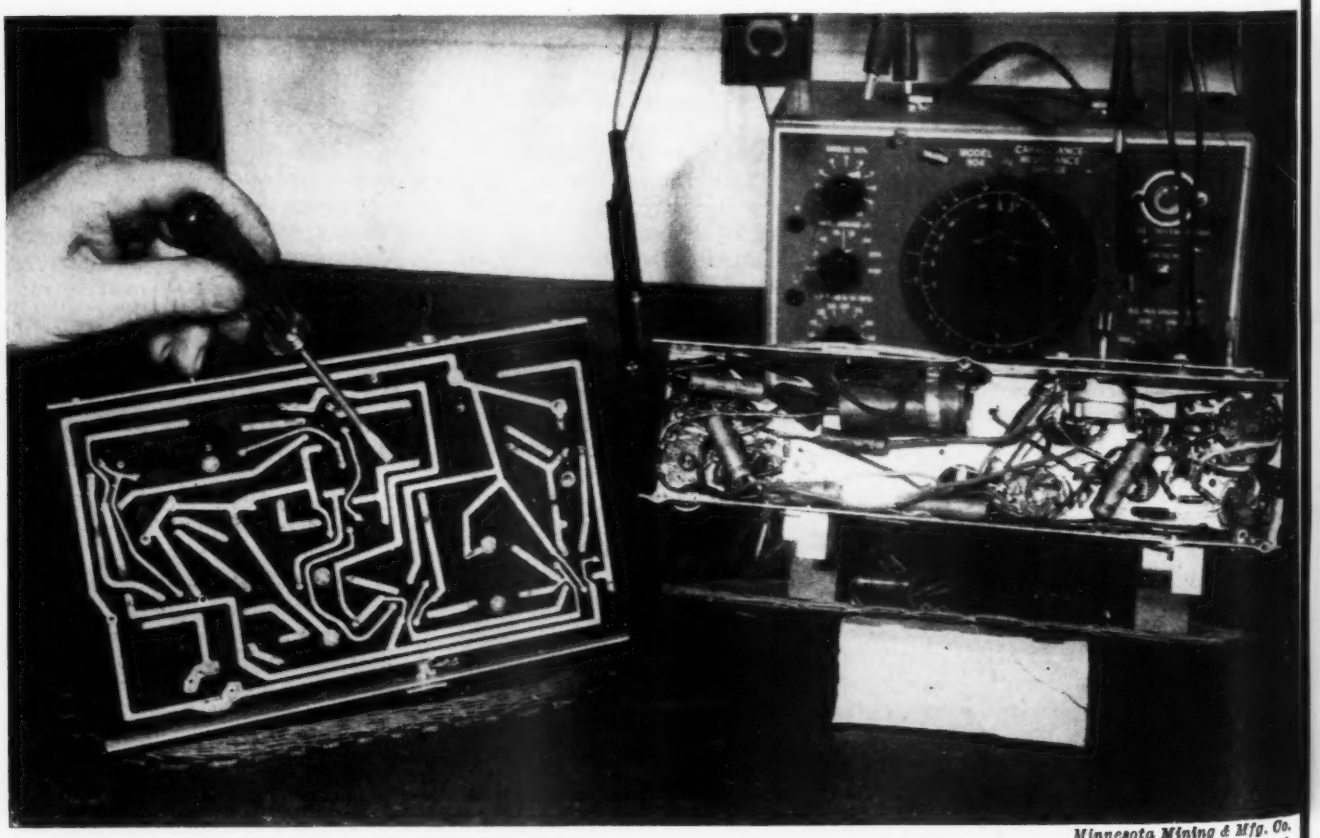
The width of conductors is ordinarily varied to match wire sizes. Corresponding wire sizes are determined from a table showing the conversion of square inches to circular mils, and showing corresponding wire gage numbers. In laboratory tests of current carrying capacity, a sprayed copper conductor 0.007 in. thick and $\frac{1}{8}$ in. wide carried a current of 17 amperes for several hours. When the current was increased to 20 amperes, the conductor failed after five minutes. This conductor was therefore considered the equivalent of a No. 23 copper wire. Another sprayed copper conductor the same thickness, but half as wide, carried a current of eight amperes for several hours. When the current was increased to 10 amperes this conductor failed after 10 minutes, hence it was determined to be the equivalent of a No. 27 copper wire. Identical results have been obtained in repetitions of these tests.

Obviously there is a practical limit to the widths of sprayed conductors, and the thickness of 0.007 in. may not have adequate current carrying capacity when that limit is reached. In such applications, thicker deposits of metal must be built up in deeper grooves in the base material. Deeper channels can be formed by extending the time of sandblasting, or by molding them in plastic materials.

The bonding between sprayed metals and suitable base materials is excellent, even under vibration and shock. Shake tests up to 10 G's for 50 cycles failed to break or loosen any sprayed connections in a model radio receiver. Sprayed metal bonds strongly with rough or porous surfaces. The sandblasting used with the process roughens base materials sufficiently to insure good adherence. With some materials, such as some plastics and glass, heating to a plastic state takes the place of sandblasting, providing a strong bond with the sprayed metal.

Conductors can be sprayed in curving patterns of any desired radius. Experiments indicate that metallized circuits can be employed for high frequencies in some applications, and that in certain cases the condenser and coil components can be sprayed simultaneously with the conductors. Distributed capacities are reduced because of the thin character of the surfaces of sprayed conductors, which are in close proximity.

Forty-two alloys are available in wire form for use in metallizing equipment. Among these are all of the commonly used conductors, including those used for high resistance requirements. The wide variety of base materials that can embody sprayed circuits includes plastics, wood, ceramics, glass, and other in-



Minnesota Mining & Mfg. Co.

Fig. 3—The contrast between a sprayed circuit model radio, left, and a conventional receiver, right. All components on the sprayed model have been mounted on the top of the chassis, and the metallized circuits are in the bottom, for easy maintenance.

sulators. Plastic chassis can be molded to desired shapes. Flexible stencils make it possible to mask surfaces that are not flat and so to spray circuits into them.

Because of the variety of its electrical requirements, radio has served as the laboratory proving ground of metallized circuits. The latest experimental 5-tube a-c, d-c sprayed circuit receiver, Fig. 3, compares favorably with conventional models now on the market. Sensitivity and selectivity meet RMA standards. Since stray capacities do not enter the circuits of this receiver, less shielding is required.

Extensive information on comparative costs must be derived from wider production experience than is now available for study. However, the speed of producing panels irrespective of the intricacies of their wiring layouts, the elimination of extensive preparing and soldering of wires, and the replacement of a manual operation with an automatic process, all point to lowered costs through sprayed circuits. The use of better and cheaper materials in panels, the reduction of rejections for faulty wiring, the cutting of inspection time, and the simplification of the mounting of parts and soldering of leads on a flat plane will also figure in cost reductions.

As an example of the speed with which panels can be spray-wired, it is possible to produce 4,500 units of simple design in four hours. These are exchange grids on flat 4 x 8 in. panels which require no eyelets. They contain about 60 in. of sprayed circuits, with 32 connections. The plastic is an inexpensive phenolic. Two heavy duty, Metco Type Y, metallizing guns are required, along with an efficient production set-up for handling. With such equipment, each circuit is sprayed in one pass. Unit cost is estimated at 0.21 cents.

One of the important advantages offered is the speed and ease with which devices made by this means can be serviced. The elimination of layers of conventional wiring makes components easily accessible for repair or replacement, and circuits are less subject to damage during servicing. The simplicity and clean appearance of these circuits can be a strong selling point for consumer goods products.

Sprayed circuits offer the designer a means of effecting innovations in the form of the product, the possibility of greater compactness in some applications, and the opportunity to incorporate a wide range of new materials.

Formulas for Spring Redesign

A. BODENSCHATZ
I.T.E. Circuit Breaker Company

OCCASIONALLY SPRINGS must be redesigned for circuit breakers and other calibrated instruments—at the cost of considerable time and effort on the designer's part. The problem usually is to reduce spring stress without changing the spring rate, installed height and solid height.

The following equations reduce the work required in solving this problem. The symbols used are defined as follows:

S = Stress, lb/in.²
K = Spring rate, lb/in.
P = Load, lb
F = Deflection, in.
G = Modulus of elasticity, lb/in.²
d_w = Wire dia, in.
N = Number of active coils in spring
D = Mean dia of spring, in.
H = Solid height, in.
OD = Original outside dia of spring, in.
OD_n = New outside dia of spring, in.
d = Differential sign

From any standard text on spring

$$K = \frac{GD^4}{8ND^3} = \frac{P}{F}, H = d_w N, N = \frac{H}{d_w}$$

If the effect of solid height is included,

$$K = \frac{Gd^4_w}{8HD^3}$$

then the derivative of K with d and D as functions of K is

$$dK = \frac{Gd^4_w}{8HD^3}\left(\frac{5}{d_w}d\,d_w - \frac{3}{D}d\,D\right)$$

From the conditions of the problem K remains constant, so $dK = 0$.

or

$$\frac{5}{d_w}d\,d_w - \frac{3}{D}d\,D = 0$$

and $$dD = \frac{5D}{3d_w}d\,d_w$$

By adding the medium dia and wire dia differentials to the original outside dia (refer. Fig 1)

$$OD_n = OD + \frac{5D}{3d_w}d\,d_w + d\,d_w$$

$$OD_n = OD + \left(\frac{5D}{3d_w} + 1\right)d\,d_w \qquad (1)$$

Eq (1) gives the new outside dia for any convenient change in wire dia. For checking stress, another equation is derived, from the standard equation

$$S = \frac{8P\,D}{\pi\,d^3_w}$$

Then the derivative of K with d_w and D as functions of K is

$$dS = \frac{8P}{\pi}\frac{D}{d^3_w}\left(\frac{dD}{D} - \frac{3dd_w}{d_w}\right)$$

Substituting

$$\frac{5Ddd_w}{3d_w} \text{ for } dD$$

$$dS = S\left(\frac{5}{3d_w} - \frac{3}{d_w}\right)d\,d_w$$

$$dS = -S\left(\frac{4}{3d_w}\right)dd_w$$

From this, the percent change in stress for a positive increase in d_w is

$$\frac{100\,d\,S}{S} = -\frac{133.3}{d_w}d\,d_w \qquad (2)$$

Using Eqs (1) and (2), the designer can choose several wire diameters and then compute the outside diameter and stress for his redesigned spring all with the same spring rate as the original spring.

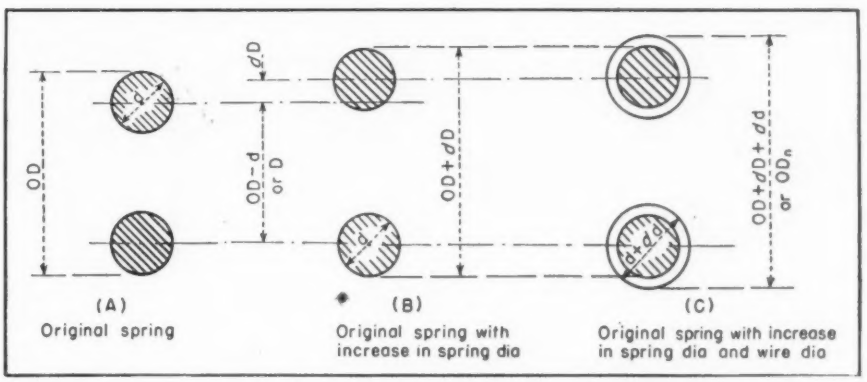
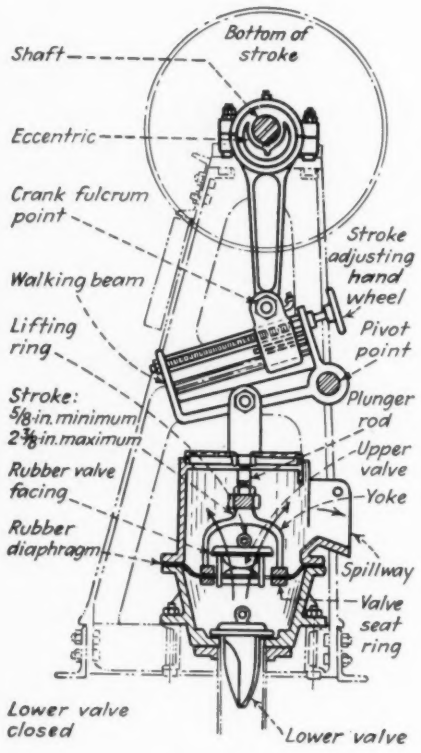


Fig. 1—Spring cross-section through one turn. Increment increases in spring and wire diameter are shown in (B) and (C).

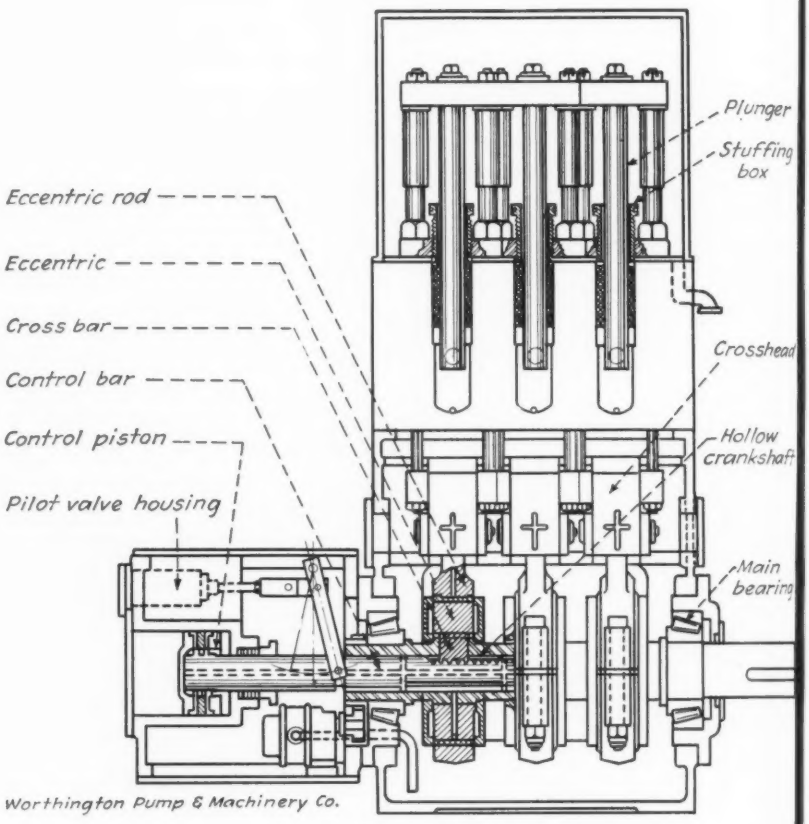
Designs and Operating Principles of Typ

Pumps showing application principles of diaphragms, and illustrating methods



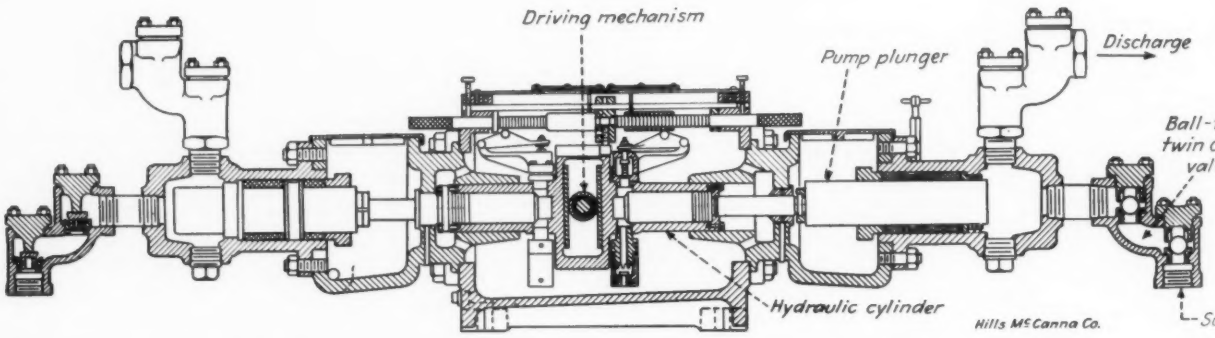
Denver Equipment Co.

17 HANDWHEEL OPERATES Acme-threaded rod, shifting crank fulcrum point on walking beam to change stroke. Solutions pumped can contain 60-70 percent solids. Used with pulp thickeners.



Worthington Pump & Machinery Co.

18 FOR USE IN PIPE LINE PUMPING, boiler feeding, and other applications requiring 0-100 percent capacity control, the Variflo is driven by a constant speed source. Capacity is varied by positioning eccentric on crank to give correct stroke. Hydraulically moved control bar engages cross bar, via inclined-plane teeth, to which eccentric is secured by tongue and groove. Torque transmitted to eccentric by crank

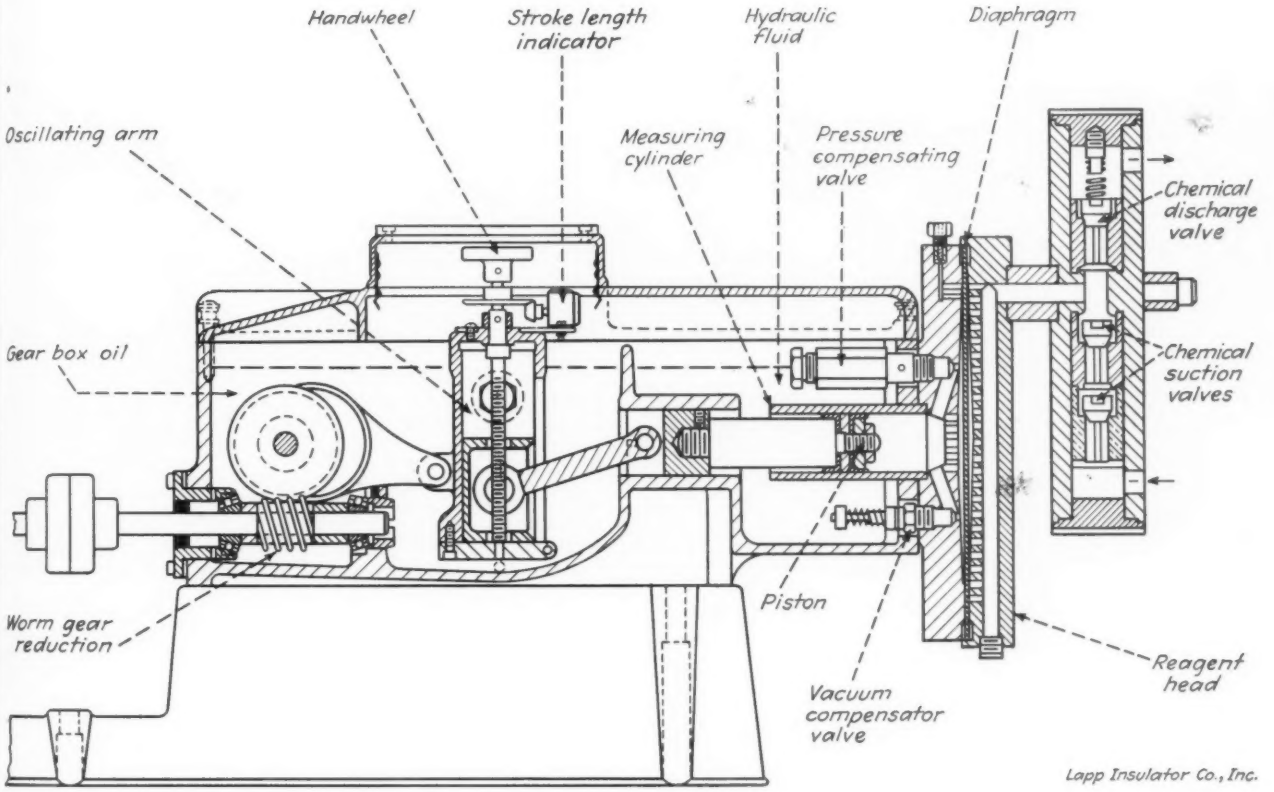


Hills McCanna Co.

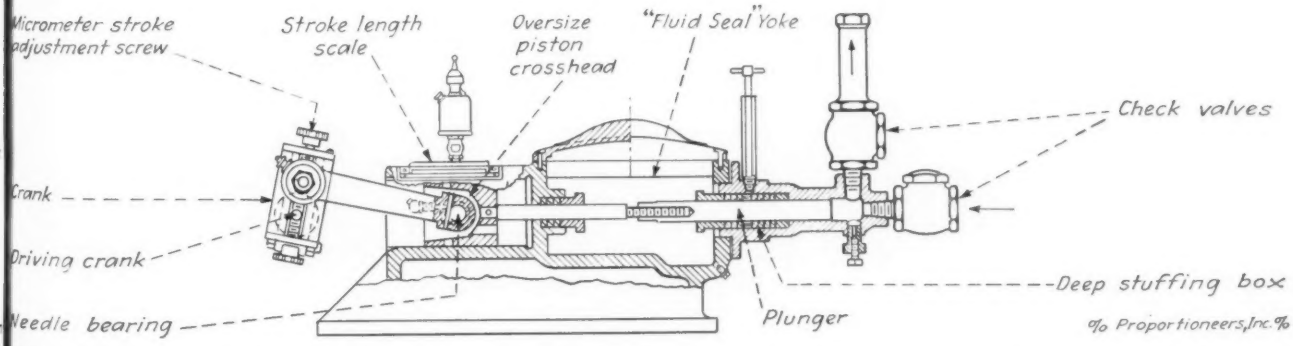
20 A CHEMICAL METERING and proportioning pump, the Type K uses a principle of hydraulic displacement as a means of stroke adjustment. A hydraulic cylinder is located between the driving mechanism and the pump plunger. Length of the pump stroke is governed directly by the amount of fluid contained in the cylinder. On discharge stroke, accurate valving permits escape of fluid until proper amount remains in cylinder. At this point, valve closes and remaining fluid acts as a solid, driving the pump plunger. The pump plunger is returned to the same starting point with each stroke regardless of the stroke length.

Typical Pumps Used in Industry—III

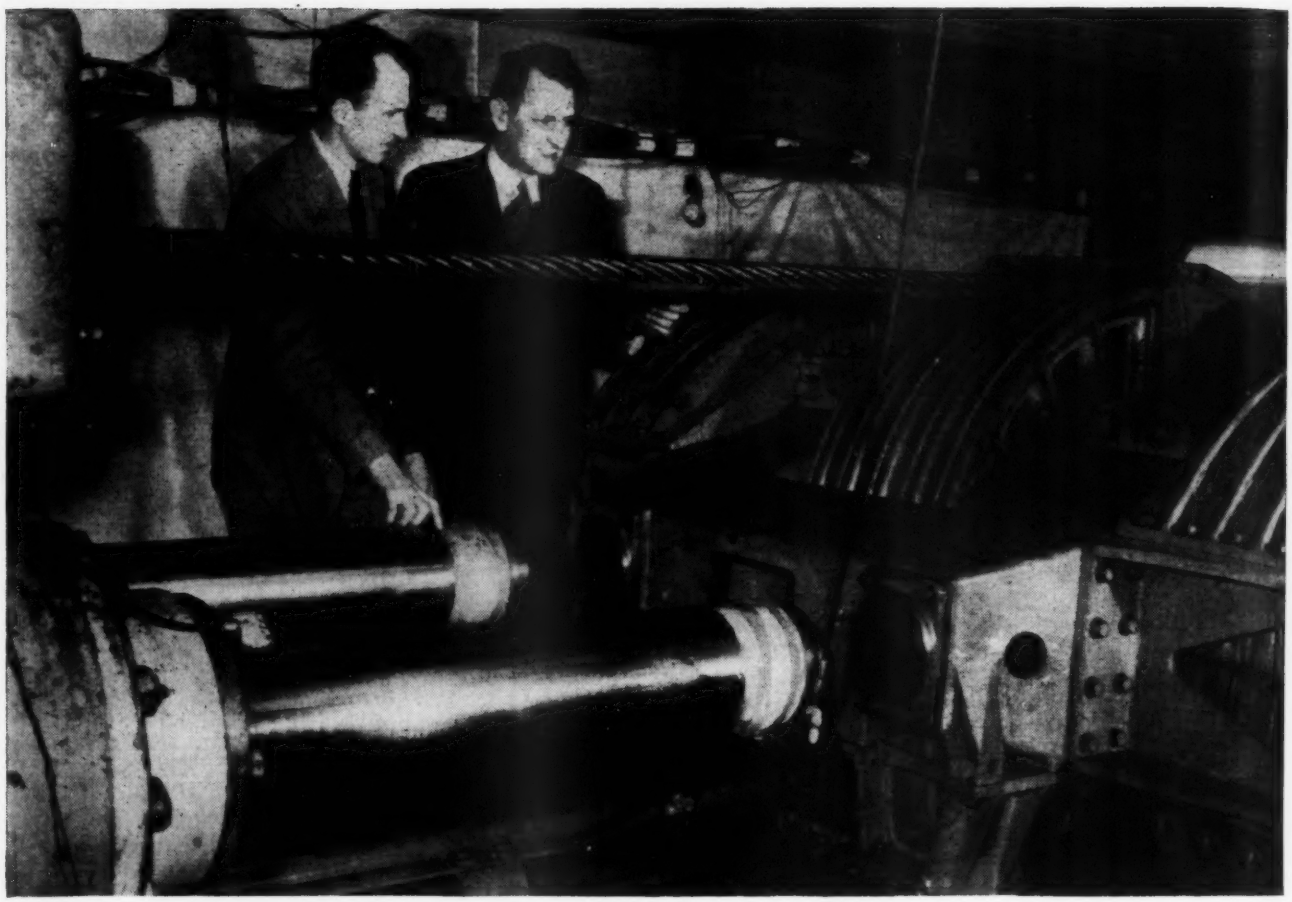
Methods for changing output in metering and proportioning liquids.



19 THE PULSAFEEDER is a combination piston-diaphragm proportioning pump. The reciprocating piston, whose stroke length is variable, displaces an accurate volume of hydraulic fluid. The regulating handwheel moves cross head link connecting-point to vary stroke. Only contact with chemicals is at the diaphragm. No stuffing box is required around piston rod. Diaphragm, metal, plastic or rubber, acts as partition between chemical and hydraulic fluids and does not fail mechanically because it is always in hydraulic balance. Gear box is filled with oil and oil in compression chamber submerges piston, cylinder and compensating valves.



21 STOPPED WITH CRANK ARM and connecting rod horizonal, stroke of the Adjust-O-Feeder can be varied to give esired metered flow. In this position, scale shows actual stroke ength. Connecting rod pin is shifted in the slotted crank arm to hange crank radius and plunger stroke. Driving crank is fitted with a shear pin to protect single reduction speed reducer. "Fluid Seal" Yoke permits use of an enclosing fluid around plunger and stuffing gland. Seal protects plunger from scoring, corrosion and chemical deposits. This single acting plunger pump has outside end packed stuffing boxes and accurate, interchangeable check valves.



HYDRAULIC CROSSHEAD BUFFERS installed on a catapult to decelerate catapult car at end of travel undergoing proof tests.

Design of Orifices For Hydraulic Shock Absorbers

Application of design equations for the selection of five types of orifices used in hydraulic shock absorbers. The performance of each type is analyzed and presented in graphical form.

JOSEPH BROWN
Analytical Engineer, Naval Aircraft Factory

IN A PREVIOUS ARTICLE appearing in the February number of PRODUCT ENGINEERING on page 92, a number of equations, useful for the design of various orifice shapes, were derived. In this article, the applicaton of these equations is taken up. In addition, the effects of friction and spring forces, fluid viscosity, elasticity and dead weight, which were neglected in the derivation of the orifice equations, are taken into account.

The equations that were derived apply to the five types of orifices shown in Fig. 1. Using the equations, the size of the orifice for each type can be found, together with the variation of cylinder pressure and piston velocity for all positions of the pistons.

Symbols and equations are restated:

SYMBOLS

a = total orifice area, in.^{2}
A = piston area, in.^{2}
C = orifice discharge coefficient,
d_c = diameter of cylinder, in.
D = piston diameter, in.
D_o = piston dia. at start of travel, in.
E = energy absorbed by fluid, ft lbs
f = acceleration, ft/sec^2
F = force on piston, lbs
g = acceleration of gravity, 32.2 ft/sec^2
p = pressure, lbs/in.^{2}
s = piston travel from start, in.
s_{max} = full stroke of piston, in.
v = velocity of piston, ft/sec
V = velocity of fluid, ft/sec
W = weight of body to be slowed, lbs
γ = density of fluid in cylinder, lbs/ft^3

EQUATIONS

$$-W\frac{dv}{v} = \gamma C^2 A^3 ds/(3456\,a^2) \qquad (1)$$

$$p = \gamma C^2 A^2 v^2/(288\,ga^2) \qquad (2)$$

$$\text{(Type 1)}\ \log_e \frac{v_o}{v} = \gamma \frac{C^2 A^3 s}{3456 a^2 W} \qquad (3)$$

$$\text{(Type 2)}\ a^2 = (v_o^2 - 2fs/12)\frac{\gamma^2 C^2 A^3}{288 fW} \qquad (4)$$

$$p = F/A = Wf/gA \qquad (5)$$

$$\text{(Type 3)}\ W \log_e \frac{v}{v_o} = \gamma \frac{C^2 A^3}{13{,}824\, d_c k\,(\ell n/2)^3}$$

$$\left[-\frac{\cos(\theta/2)}{(\theta/2)} - \frac{\theta}{2} + \frac{(\theta/2)^3}{3\lfloor 3} - \frac{(\theta/2)^5}{5\lfloor 5} + - - + - -\right]_{\theta_0}^{\theta} \qquad (6)$$

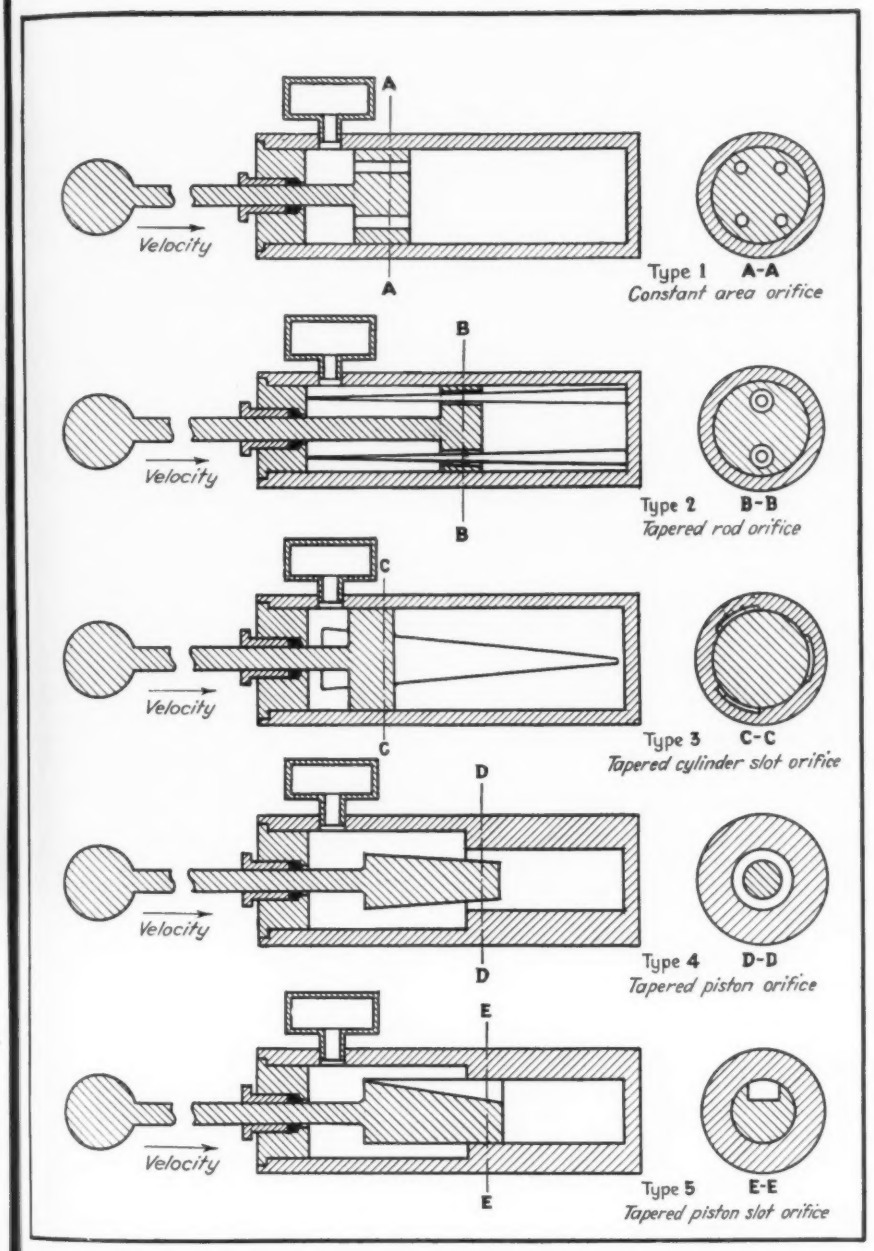


Fig. 1—Five types of orifices commonly used in hydraulic shock absorbers.

(Type 4) $$W \log_e \frac{v_0}{v} = \frac{C^2 \gamma}{8800k} \left[D^6 \frac{+ 5d^2_c D^3 - (15/2)\, d^4_c\, D}{3(d^2_c - D^2)} + \frac{5d^3_c}{4} \log_e \frac{d_c + D}{d_c - D} \right] \frac{D}{D_o} \qquad (7)$$

(Type 5) $$W \log_e \frac{v}{v_0} = \frac{C^2 \gamma}{3456k} \left[\frac{- A^3}{a} - 3A^2 \log_e a + 3Aa - \frac{a^2}{2} \right] \frac{a}{a_o} \qquad (8)$$

Comparison of Different Type Orifices

To illustrate the application of the equations, a typical shock absorber problem will be considered. The various orifices sizes will be calculated and the performance of a shock absorber equipped with each type of orifice will be analyzed in terms of cylinder pressure and piston velocity versus piston stroke.

Problem

A 1000 pound weight, traveling at the rate of 100 ft per sec is to be brought to rest in a distance of 3 ft. Space limitations require that the piston diameter be approximately 6 in.

Type 2 Orifice

The problem is first worked out for this type orifice because the solution is simplest and also gives a clue as to the size of the other types of orifices.

For constant deceleration $v^2 = v_o^2 - 2fs/12$

$f = 100^2/2 \times 3 = 1667$ ft/sec^2

From Eq. (5), $p = Wf/gA = \dfrac{1000 \times 1667}{32.2 \times .7854 \times 6^2} = 1830$ psi

From Eq. (4) $a^2 = (v^2_o - 2fs/12) \times (\gamma\, c^2 A^3/288fW)$

a will be maximum when $s = 0$.

Therefore $a^2_{max} = \gamma\, C^2 A^3 v_o^2/(288fW)$

If the hydraulic fluid used is a mixture of 80% glycerine and 20% distilled water, then $\gamma = 76$ lbs per cu ft. An average value of C may be taken as 1.2.

Then $a^2_{max} = 76 \times (1.2)^2 \times (0.7854 \times 6^2)^3 \times 100^2/288 \times 1667 \times 1000 = 7.16$ in.^{2}

At the end of the piston travel, $a = 0$, by substitution in Eq (4).

The value of a at any other station may be obtained also by substitution in Eq (4).

Type 1 Orifice

Assume that the orifice area is equal to the average of the end orifices areas of type 2. By using this value in Eq (3), it is seen that a slightly smaller orifice ($a = 3$ in.^{2}) is needed to bring v down to a reasonable value. Substituting in Eq (3), we have:

$\log_e (v_0/v) = \gamma\, C^2 A^3 s/(3456a^2 W)$

$\log_e (100/v) = 76 \times 1.2^2 \times (0.7854 \times 6^2)^3 s/(3456 \times 3^2 \times 1000)$,

from which it is possible to solve for values of v for corresponding values of s. By using Eq (2) also, the following table has been prepared.

s	0	2	4.5	9	18	27	36
v	100	85.2	70	49	24	11.7	5.75
p	10500	8260	5600	2520	604	153	34.7

Type 3 Orifice

By observing the variation of the type 2 orifice, type 3 orifice may be proportioned similarly, except that a slightly larger orifice should be used in the beginning, because the average orifice used for type 2 is larger than the arithmetic mean of the end orifices. The total orifice areas therefore may be set to vary between 8 in.^{2} and $\frac{1}{4}$ in.^{2} divided among three orifices. The piston diameter is 6 in., and the depth of slot is $\frac{3}{4}$ in.

The central angle subtended by each orifice will then vary between 60.4 and 1.9 deg for which the corresponding chords will be 3.4 in. and 0.111 in. This will give a value for $k = 0.0915$. By the use of eqs (6) and (2) the following table is computed,

Note that in Eq (6),

t = depth of slot = $\frac{3}{4}$ in.
n = number of slots = 3
θ = Central angle subtended by slot, radians

$$k = \frac{x_o - x}{s}.$$

Where x_o = max width of slot
x = width at given station
s = piston stroke from initial position

s	0	3	9	12	18	22½	27	30	36
x	3.4	3.13	2.59	2.30	1.75	1.34	0.93	0.66	0.11
θ	60.4	55.2	44.4	40	30	45.3	15.82	11.2	1.89
a	8.00	7.31	5.88	5.30	3.97	3.03	2.09	1.48	0.25
v	100	93.2	85.7	78	64.6	50.7	24.9	12.1	0
p	1477	1530	2000	2040	2570	2713	1365	645	0

Type 4 Orifice

For the tapered piston, it is possible to use the same initial orifice area as for type 3 orifice. However the end orifice is dictated more by piston clearance than anything else. Assuming a piston whose initial diameter is 5.08 in. (giving an orifice area of 8 in.²) and whose final diameter is 5.938 in. and an inside diameter of 6 in. for the cylinder $k = 0.01192$ where

$$K = \frac{D - D_0}{2s}$$

s	0	9	18	22	27	29½	32	36
D	5.08	5.25	5.51	5.604	5.724	5.784	5.843	5.938
v	100	90.7	78.5	70.3	53.9	42.2	24.5	0
a	8	6.29	4.4	3.7	2.59	1.96	1.414	.55
p	1477	1970	3000	3310	4080	4370	2840	0

Type 5 Orifice

Here again the same end orifices areas as type 3 orifice are assumed, or an initial area of 8 in.² and an end orifice area of ¼ in.² Hence $k = 0.215$, where

$$k = \frac{a_0 - a}{s}$$

Using Eq (8) and Eq (2), the following table is computed:

s	0	9	18	27	30	36
a	8	6.065	4.13	2.2	1.55	0.25
v	100	93.6	82.2	49.5	33.4	0
p	1477	2250	3740	4800	4380	0

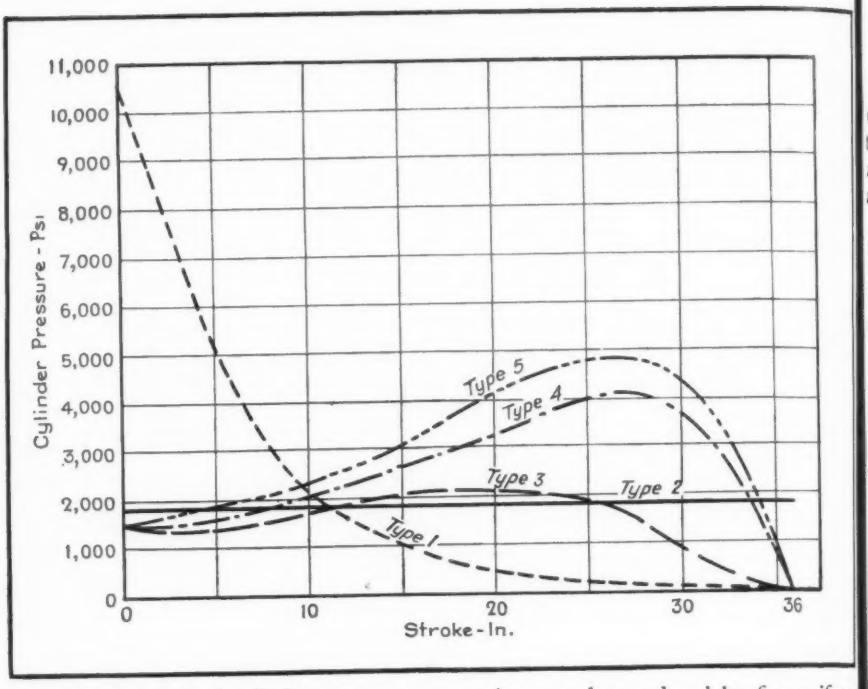


Fig. 2—Variation of cylinder pressure versus piston stroke produced by five orifices.

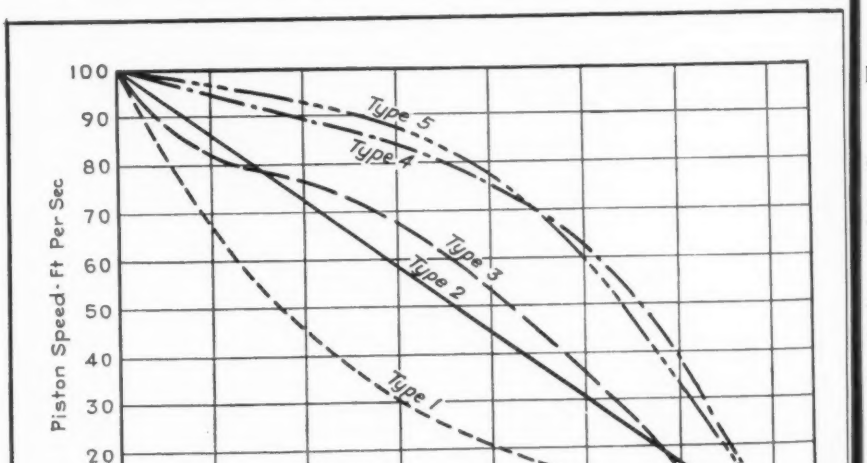


Fig. 3—Variation of piston speed versus stroke produced by five types of orifices.

Comparison of the Orifices Used

Performance curves for all five orifice types are shown in Figs. 2 & 3. The effect of orifice configuration on shock absorber performance is quite apparent. Except for the constant area orifice, the other orifices do not produce marked differences in shock absorber performance. The principal reason for pressure variations is that for the type 3 orifice, the piston area remains at its maximum value for the entire stroke, but in the other cases, part of the piston area has been cut away to provide orifice area. For a well proportioned orifice configuration, it is seldom necessary to use an expensive constant deceleration system. The high pressures produced by the constant orifice (type 1) restricts its use to small mechanisms, where high cylinder pressures will not overstress a relatively thin cylinder wall.

Effect of Friction and Spring Forces

In the foregoing discussion, piston velocity is assumed to be affected only by orifice size. This is the ideal case assuming that friction is negligible. However, any or all of the following forces may exist: mechanical friction, restoring forces exerted by springs for returning the piston to zero position, packing friction, viscous friction, mechanism weights when arranged in a vertical direction, and hydraulic fluid elasticity. Viscous friction and fluid elasticity will be taken up later. The method of including constant and variable resistances will be considered here.

Kinetic energy to be dissipated $= Wv^2/2g$

Frictional energy (mechanical and packing) $= K_1 s/12$ Where K_1 = friction load

Spring energy

$$= \int (s_o + s)\ K_2\, ds/12 \text{ where}$$

s_o = precompression, in.
K_2 = spring constant, lbs/in.

For a constant deceleration orifice (type 2), merely subtract the frictional energy from the kinetic energy and solve for the necessary orifice area, a, in the equation below:

$$W(v_o^2 - v^2)/2g - (s_o + s)\ K_2 s/24 - K_1 s/12 = \gamma\ c^2 V^2 A^3 s/(3456\ g a^2).$$

For all other cases the procedure is as follows.

The energy equation is

$$W(v_o^2 - v^2)/2g = \int_0^s \frac{\gamma\ C^2 v^2 A^3 ds}{3456 g a^2} + \int_o^s K_1 \frac{ds}{12} + \int_o^s \frac{(s_o + s)\ K_2 ds}{12}$$

Differentiate the energy equation shown above.

$$-Wv\,dv/g = K_3 v^2 A^3\,ds/a^2 + (K_1 + K_2 s_o)\,ds/12 + K_2 s\,ds/12 \text{ where } K_3 = \gamma\ c^2/3456g$$

Divide through by ds

$$\frac{-Wv}{g}\ \frac{dv}{ds} = K_3 v^2 A^3/a^2 + (K_4 + K_2 s)/12 \text{ where } K_4 = K_1 + K_2 s_o$$

Let $v = \sqrt{y}$

Then $$\frac{W}{2g}\ \frac{dy}{ds} \frac{-K_3 A^3 y}{a^2} = \frac{K_4 + K_2 s}{12}$$

This equation is a linear, first order differential equation, the solution of which is:

$$y = v^2 = e^{-\int K_3 2g\ A^3 ds/(Wa^2)} \left\{ -\int e^{\int K_3 2g\ A^3 ds/Wa^2} 2g\,(K_4 + K_2 s) ds/12\ W + C \right\} \quad (9)$$

from which it may be seen that for $s = 0$, $C = v_o^2$.

It may be noted that the value of $\int K_3 2g A^3/(Wa^2)\ ds$ may be computed directly by multiplying the right side of Eqs (3), (5), (6) and (7) by $2/W$.

In order to obtain an idea of the comparative effect of friction forces, their effect on piston speed will be considered. Using an orifice of type 5, assume that there is constant mechanical friction force of 250 pounds due to a coefficient of friction of 0.25. Also that there is a constant packing force of 960 pounds. This value is determined by multiplying the highest pressure to be encountered by 0.2. There is also a spring retarding force which varies from 1000 pounds at the beginning of the stroke to 2000 pounds at the end of the stroke. Let the problem be to determine the velocity of the piston at 18 in. or 50 percent of the stroke.

By Eq (9)

$$\int_0^s K_3 \frac{2g A^3}{Wa^2}\,ds = \frac{2W}{W} \log_e (v/v_o) = -0.391$$

Also

$$K_4 = K_1 + K_2 s_o = 250 + 960 + 1000 = 2210$$

Substituting in Eq (9) and solving using step-by-step integration, $v = 81$ fps compared to 82.2 fps calculated without including friction effects. In this case, the effect of friction is negligible; but it cannot be assumed that the difference will be negligible every time. Usually friction effect may be neglected in making the first approximation for orifice size.

Effect of Viscosity

Friction losses due to fluid viscosity are small in shock absorber design. In the problem chosen as an example for this article, assume piston has traveled 2 in. The coefficient of viscosity, $\mu = 0.00003$ lb sec/sq ft Assume an orifice of type 3 is used.

$$F_v = \mu\alpha\ V/y = \mu\alpha\ Av/(ay)$$

where a = circumferential area of the piston.

$$F_v = \frac{3 \times 10^{-5} \times 6\pi \times 2 \times 0.7854 \times 6^2}{144 \times 0.75/12} \frac{v}{a}.$$

F_v, for a velocity of 100 fps, will then be approximately ½ lb, which is negligible compared to a hydraulic force averaging about 40,000 lb.

Effect of Fluid Elasticity

The average volume modulus of elasticity of water at an operating pressure of about 4000 psi is 330,000 psi.

Also $E_v = -V\ dp/dv$ where
E_v = volume modulus of elasticity, psi
p = pressure, psi
V = volume, cu ft

If the maximum pressure developed using type 1 orifice, is 10,500 psi, (refer Fig. 2) and the volume of the fluid as 0.59 cu ft, then $V = -0.59 \times 10{,}500/330{,}000 = 0.0188$ cu ft compression. This amounts to a linear displacement (using ½ ft dia) of 0.0957 ft. The work absorbed by this compression is $\frac{1}{2} \times 0.0957 \times 10{,}500 = 503$ ft lb, which amounts to about 3% of the original kinetic energy. However when it is considered that the pressure is reduced to zero by the time the piston reaches the end of its travel, it may be seen that the energy of elasticity has been reduced considerably.

However, for type 2 orifice where the pressure does not reach zero, but remains constant, it must be realized that the stored energy has not been dissipated, and this effect must be taken into account when proportioning the mechanism dimensions. However, in the problem considered in this discussion, p is only 1830 psi; consequently the amount of stored energy is negligible.

It will be noted that the foregoing discussion did not include such effects as initial impact or elasticity in the weight to be stopped. In most cases these phenomena can be disregarded. However, any study including impact and weight, elasticity can be undertaken by using the foregoing relationships as a basis.

Aluminum and Magnesium Welding

THERE HAS BEEN LITTLE industrial experience in the fabrication of light alloy structures by welding wrought sections thicker than one inch, according to a report prepared by researchers of the Batelle Memorial Institute, working under contract with the Office of the Chief of Ordnance, Department of the Army. There has been shielded arc welding of hot-rolled magnesium plate on 1 in. material.

Most magnesium alloys are produced in two tempers: work-hardened and annealed. In areas adjacent to the weld, the structure produced by cold work recrystallizes from the effect of welding heat and the joint tends to have properties characteristic of the annealed condition. Since the compositions of wrought magnesium alloys usually preclude their improvement by heat-treatment, maximum joint efficiency is generally obtained when welding the annealed temper.

Data is not available on heavy welded sections of high strength aluminum alloys. But tests on light sections indicate that with available processes and alloys, no improvement in joint efficiency is to be anticipated by increasing section thickness.

Flash and pressure welding methods are now in development stages for both aluminum and magnesium. Both methods offer the advantage that no extraneous filler material is required for the joint. Pressure welding has the added advantage that the bond is obtained without fusion.

Mimeographed copies of the report (PB-78712, "Survey on Welding of Aluminum and Magnesium"), 298 pages, cost $8. Orders addressed to the Office of Technical Services, Department of Commerce, Washington 25, D. C. should be accompanied by check or money order payable to the Treasurer of the United States.

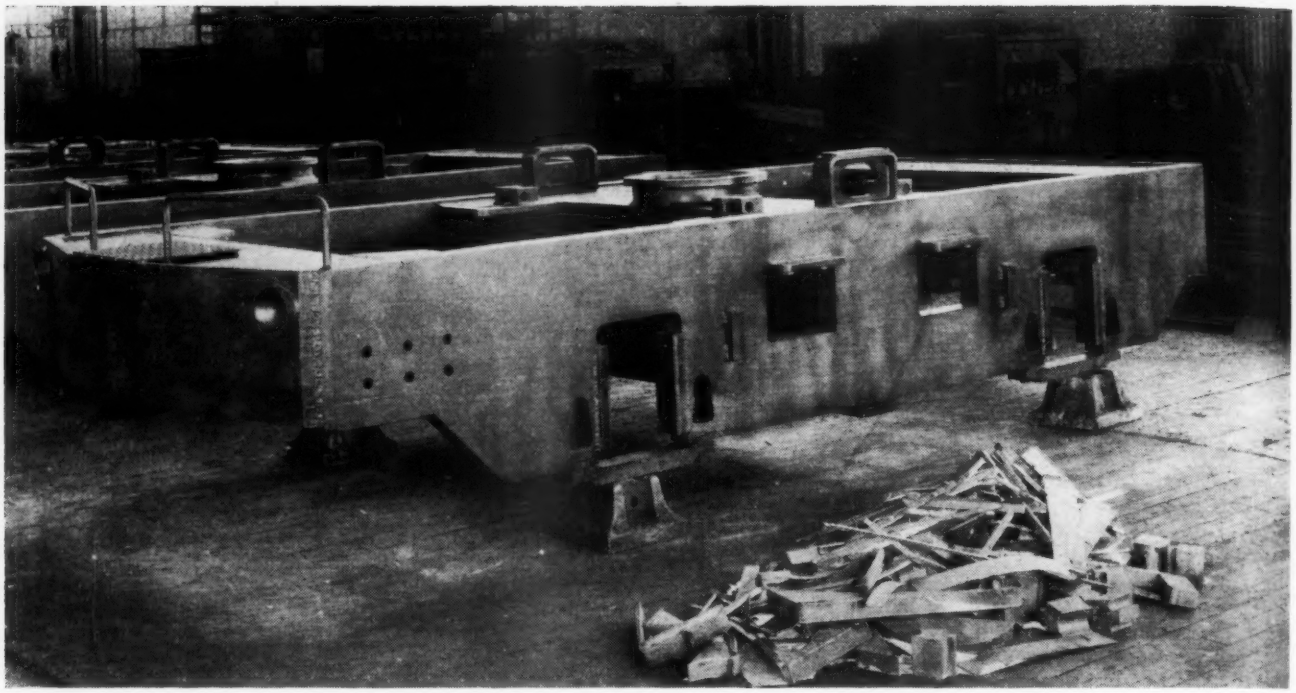


Fig. 1—Only 3,200 lb of scrap remained after fabricating 32 tons of steel to make four of these truck frames for a 100 ton electric locomotive. Such a high utilization of material is only possible by careful planning during the design stage.

Designing for Low Scrap

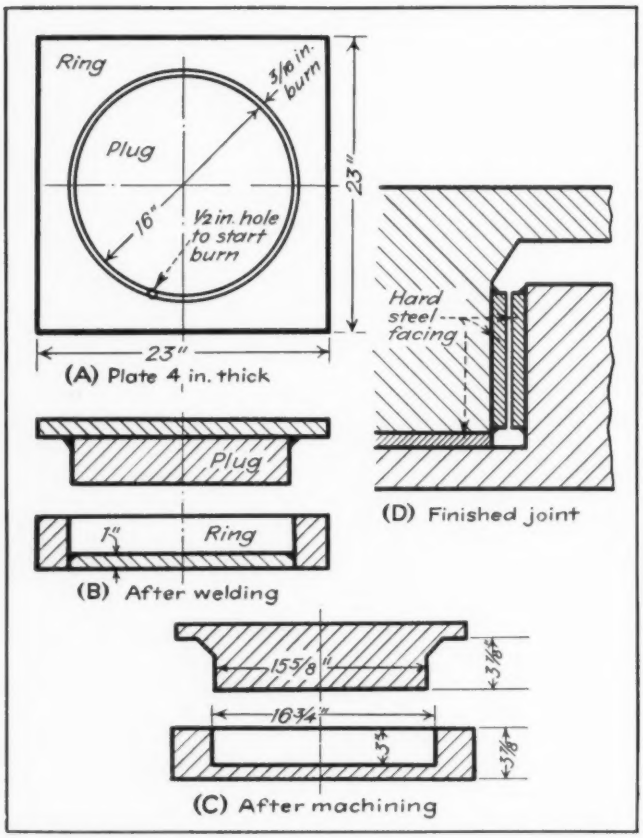


Fig. 3—Sequence of steps for maximum utilization of material for fabricating large pivot bearing from steel plate. Stainless steel welding rod is used for joining the hardened steel facing.

BETTER UTILIZATION OF MATERIAL for fabricating parts from metal plates and shapes often is an effective way for the designer to reduce unit costs. But to avoid any increases in labor or overall cost, the planning must be done in the design stage. Some idea of the results of such planning by the designer for maximum use of purchased material is shown in Fig. 1. Each of the four trucks frames with equalizer bars weighs 13 tons; but the scrap is only 800 lb. or about 3 percent. Properly approached, less scrap from purchased material usually results in use of both less raw material and lower labor costs.

For best results, it is essential for the designer to have a reasonably clear and complete picture of the overall machine. A piece removed from one part to make an opening, may be used to make entirely unrelated parts in the machine. For instance, often brackets or braces can be applied without change from parts as burned; thus providing these parts with only the labor necessary to produce the larger unit.

An example of what can be done by a brief study and redesign is shown in Fig. 2. A set of four curved beams as originally laid out required a plate of the size shown in Fig. 2 *(A)*. Without weakening the beam in its critical section, the shape was changed to obtain better nesting, which reduced the size and cost of the plate.

Even more important, burning time was considerably less since each cut produced two edges for considerable distance on the redesigned bar as shown in Fig. 2 *(B)*. By cutting additional brackets from the larger pieces of scrap, the usable percentage of purchased plate was increased from 62½ percent to 85 percent. Since such parts are burned by means of a guide track cut in a large board, no increase was necessary for either layout or board.

Another example of designing for maximum economy

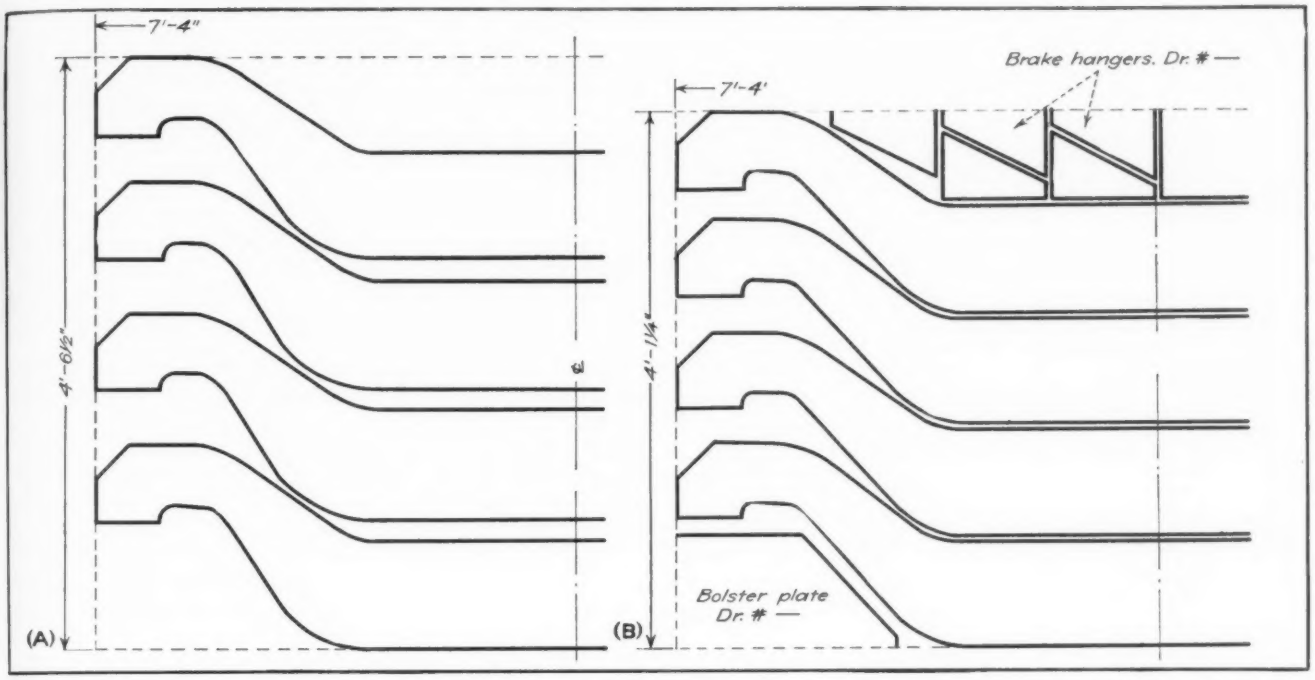


Fig. 2—Design change that saved material and labor. (A) Original layout used only 62¼ percent of steel plate (B) Redesign reduced size and cost of plate and uses 85 percent of the material. Two edges are burned at once for much of the cutting pass.

To Reduce Cost

E. F. McCALEB
Design Engineer, General Electric Company

of material is shown by the large pivot bearing in Fig. 3. Typical uses for such bearings are in positioning machines for welding, or as center plates between platform and truck on locomotives. Only one 4 in. plate is purchased and both pivot and bearing are fashioned from this plate with one flame cut, as shown in Fig. 3 *(A)*. The plug is then welded to a 1 in. plate to form a backing, and a similar 1 in. filler plate is welded in the ring, as shown in Fig. 3 *(B)*. Both plug and ring are completely machined as shown in Fig. 3 *(C)*. To provide the bearing faces, hardened bands of SAE-1045 steel are welded with stainless steel welding rod to both pieces of the center plate for locomotive use as shown in Fig. 3 *(D)*.

For the pivot bearing, a bronze ring is machined with the proper clearance between the surfaces and inserted in the gap, with a bronze plate in the bottom for withstanding the thrust.

The method for manufacturing some designs will depend on the question of utilization of scrap. The bolster plate shown in Fig. 4 *(A)* can be made from two plates as shown in Fig. 4 *(B)* with complete usage of material, but with a certain amount of joint preparation, welding, and subsequent straightening. But if some use can be found for the parts marked *X* the bolster plate can be produced more economically from a single plate.

Opportunities for reduction of scrap occur most frequently in the design of structures where weight is desirable and where the material is purchased to size from the mill.

With the lighter sheets used in cab structures, standardization of parts across an entire line often offer potential savings in both material and labor.

For example, previously sand box filler openings in cab sides were cut out on the nibbler with a consequent

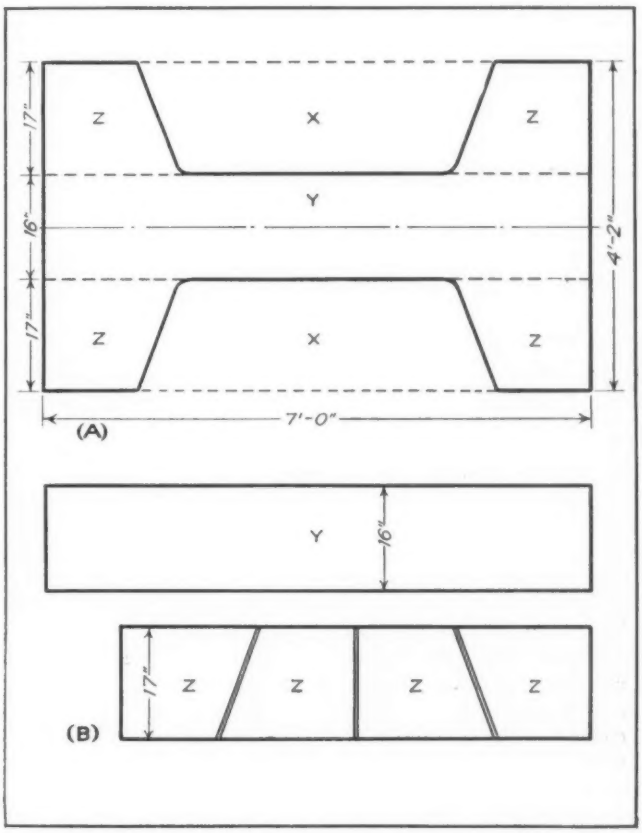


Fig. 4—Manufacturing economy often depends on finding use for scrap. (A) If X can be used, make bolster from single plate; otherwise fabrication from two plates, as in (B), is lower cost.

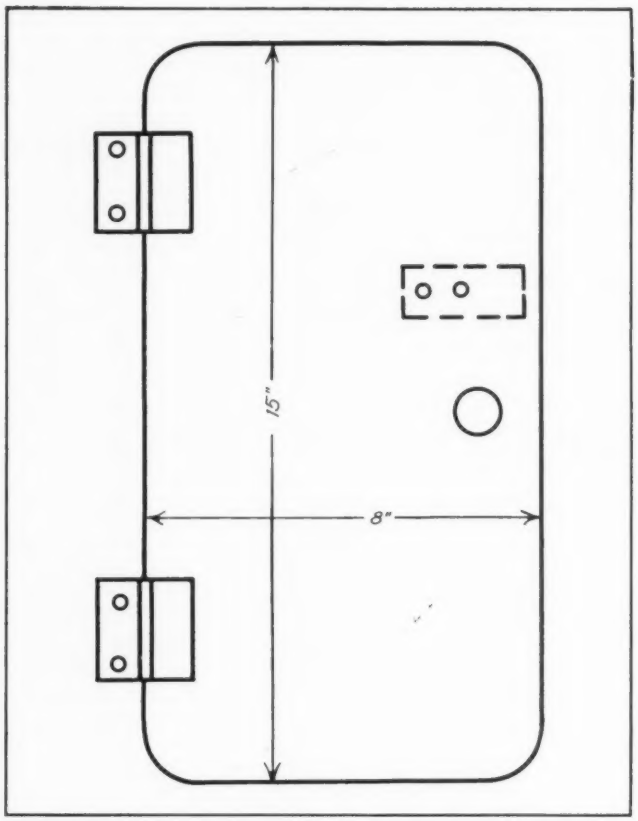


Fig. 5—Lower overall cost obtained by blanking out standardized openings and using the blanked out parts for the doors.

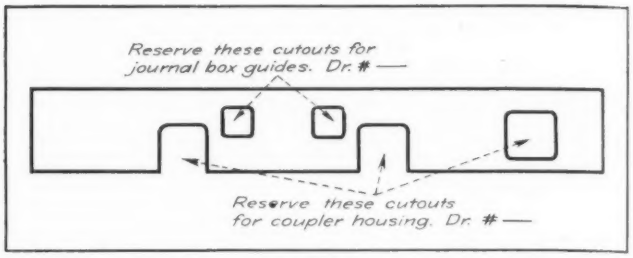


Fig. 6—Drawing of a frame with all scrap reserved. When practicable, use combination template to reburn scrap to final shape while in original setup.

loss of time in fitting the door. By standardizing the size of the opening on all models, the increased production justified a blanking die to make the opening. Use of the blanked out piece as the door, required very little fitting as shown in Fig. 5. While the material saving was only a minor item, a better product at a lower overall cost was achieved.

To be effective, it is imperative that such planning be done in the design stage. Drawings must be marked so all parts that are to be made from the saved scrap pieces can be identified.

This is an advantage, even where the pieces cannot be applied in their original state without extra burning. For example, it is often possible to incorporate the reburning of these pieces in the main burning template, thus saving setup and extra handling. One method is shown in Fig. 6, although it is more positive to actually detail the parts to be used on the burning drawing, as in Fig. 2 so the combined burning operation will not be overlooked.

Powder Metallurgy Applications and Techniques

MAINTENANCE OF CLOSE TOLERANCES, shorter manufacturing time, less scrap waste and higher production rates are among the advantages of powder metallurgy processes.

These are conclusions reached by an Office of Technical Services report prepared because of large demand for information from business and industry. The report, prepared by Ornan B. Smart, OTS inquiry section, is a general survey of the techniques and applications of powder metallurgy as they are now practiced by American industry.

As a guide to those who contemplate manufacturing powder metal parts, certain advantages have been noted: Metals too tough and with melting points too high to be worked by conventional methods may be processed by powder metallurgy; powder metal products with extremely high surface finish can be produced without secondary finishing; precision parts such as vee blocks, plug gages and micrometer frames hard enough to cut glass, are produced 75 percent complete by powder metallurgy and require only a final machining operation; and the method eliminates many secondary operations and lends itself particularly to the production of built-in lubrication for moving parts.

However, the method does have drawbacks. Initial outlay for equipment is large; close production control is essential, raw materials are expensive, parts produced by other methods are more easily machined, tool and die costs are high; since powder metals do not flow, the design and size of parts is limited; special problems arise in plating powder metal parts because their porosity permits absorption of liquids or salts in plating solutions, and workers in this field must be highly skilled.

Practically all industrial metals can be used in powder form, the report states, and some of the important metal—columbium, tantalum, tungsten, molybdenum—are reduced from ores in powdered form. Using powder metallurgy, duplex alloys can be produced which retain the individual characteristics and properties of each constituent. Such combinations are particularly important in the electrical industry for making electric contacts, electrodes, copper-graphite and copper-silver motor brushes, cemented carbide cutting tools, and diamond impregnated cutting and grinding wheels.

In quantity production, the automotive and aircraft industries lead in use of powdered metal products in the form of gears, cams, bearings, sleeves, bushings, rings and filters.

The method can be used for fabrication of parts ranging from 0.001 oz to 95 lb in weight and from 0.001 sq in. area to 20 in. diameter. Powder metal techniques are mainly used for making small to medium sized parts, since the larger the parts to be made, the greater the compacting pressure needed and the more complicated and expensive the tooling required.

Orders for the report (PB-81841; "Powder Metallurgy"), 47 pages, cost $1, and should be addressed to the Office of Technical Services, Department of Commerce, Washington 25, D. C., and should be accompanied by check or money order, payable to the Treasurer of the United States.

A Magnesium Alloy for High Temperature Application

Foreign Abstract, condensed from "Magnesium-Cerium-Zirconium Alloys: Properties at Elevated Temperatures," by A. J. Murphy and R. J. M. Payne. Published in the *Journal of the Institute of Metals* (London), Vol. 73, Part 3, 1946.

A SHORTCOMING of magnesium-aluminum alloys has been the tendency to creep under small loads at elevated temperatures. In this respect magnesium alloys are markedly inferior to the aluminum alloys such as D.T.D. 133c and 287. The investigation described had as its object the establishment of a magnesium alloy having improved characteristics at elevated temperatures; and thus to make possible further economy of weight in stressed light-alloy castings operating at high temperatures.

Four alloys were prepared having the compositions given in Table I. Values given for cerium content in Table I and elsewhere in this paper represent the total content of rare-earth metals. No attempt was made to distinguish between cerium and other metals of the rare-earth groups. No evidence was found to suggest that the proportions of the different rare-earth metals would affect the results given.

Alloy "B" was made to test whether the high oxidation rate of plain magnesium-cerium alloys when molten could be reduced effectively by the addition of calcium. Alloys "C" and "D" were made to determine the effect of zirconium on the casting qualities and the mechanical properties of the magnesium-cerium alloys. The alloys were prepared by a normal melting technique which involved the use of fluxes. None of the melts was superheated to a temperature appreciably above that required for casting. The small porportion of calcium in alloy "B" was found to be effective in reducing the tendency of the metal to oxidize during casting.

Table I—Composition of Alloys Used for Exploratory Tests

Alloy	Composition, Percent			
	Cerium	Zirconium	Calcium	Magnesium
A	3.01	....	.....	remainder
B	3.5*	....	0.125*	remainder
C	3.10	0.46	.....	remainder
D	1.81	0.47	.....	remainder

* Nominal.

Table II—Mechanical Properties of Magnesium-Cerium Alloys at Room Temperature

(SAND-CAST D.T.D.-PATTERN TEST BARS)

Alloy	Melt No.	Alloy Composition, Percent			0.1 Percent Proof Stress, tons per sq. in.	Ultimate Tensile Strength, tons per sq. in.	Elongation, Percent
		Ce	Zr	Ca			
A	14E	3.01	....	.....	3.4	5.8	1
B	15E	3.5*	....	0.125*	3.55	5.95	1
C	20E	3.10	0.46	.....	5.35	8.5	3
D	21E	1.81	0.47	.....	4.2	8.8	6.5

* Nominal

Table III—Mechanical Properties of Magnesium-Cerium-Zirconium Alloys at 200 C

Short-time tests. Sand-cast D.T.D. test bars
Values quoted represent the mean of two individual tests.

Alloy	Melt No.	Alloy Composition, Percent		Ultimate Tensile Strength, tons per sq in.	Elongation, Percent
		Ce	Zr		
C	20E	3.10	0.46	8.7	13.0
D	21E	1.81	0.47	7.9	19.5

CASTING TESTS

Susceptibility to hot-cracking was checked by trial castings of shapes that had previously been proven to be a sensitive test for hot-shortness. Preliminary tests showed that magnesium-cerium alloys with and without zirconium were castable, at least in fairly simple form. Subsequent experience showed that the casting qualities of the alloys were good, even for complex designs.

MECHANICAL PROPERTIES AT ROOM TEMPERATURE

Sand-cast D.T.D. pattern test bars made from the four alloys were tested at room temperatures with the results given in Table II. Values given are the mean of not less than two tests. Mechanical properties of the plain magnesium-cerium alloys are poor. Grain refinement resulting from the addition of zirconium has considerably improved these values.

SHORT-TIME TENSILE TESTS AT 200 C

Results of short-time tensile tests at 200 C on two magnesium-cerium-zirconium alloys are given in Table III. Test samples were held at 200 C for ½ hr before testing.

As a basis for comparison, standard

Table IV—Mechanical Properties of Magnesium-Cerium Alloys after Heat-Treatment

Sand-cast D.T.D. test bars heated 8 hr at 570 C and cooled in air. Tested at room temperature.

Alloy	Melt No.	Alloy Composition, Percent			0.1 Percent Proof Stress, tons per sq in.	Ultimate Tensile Strength, tons per sq in.	Elongation, Percent
		Ce	Zr	Ca			
A	14E	3.10	....	.....	3.1	5.95	1.5
B	15E	3.5*	....	0.125*	3.6	6.6	1.5
C	20E	3.10	0.46	.....	4.8	8.4	4.0
D	21E	1.81	0.47	.....	3.95	8.85	6.0

* Nominal.

magnesium-aluminum casting alloys tested under the same conditions give values for ultimate stress and elongation of approximately 10 tons per sq in. and 10 percent respectively.

Effect of Heat-Treatment on Mechanical Properties

Solution heat-treatment was conducted to determine whether the mechanical properties of the four alloys could be improved. The results of this test are given in Table IV.

Values in Tables II and IV reveal that heat-treatment has little effect other than to decrease proof stress. This is caused by structure breakdown.

Changes in the Brinell hardness of the material were insignificant. Subsequent annealing of the solution treated and water-quenched material at various temperatures led to no remarkable results. In no instance were changes greater than ten units on the Brinell scale.

A test made with a simple 3.5 percent cerium alloy showed that superheating the melt to 900 C was without effect on the microstructure of the alloy or its mechanical properties.

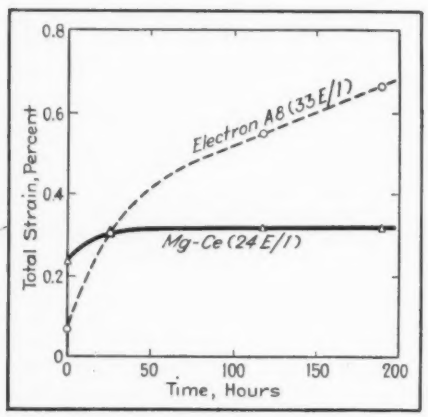


Fig. 1—Materials: Elektron A8 (as cast) and magnesium +1.81 percent cerium. Stress: 2 tons per sq inch. Temperature: 200 C.

Creep Tests

Using a simple creep test apparatus comparison tests were made between a magnesium-cerium alloy and Elektron A8 (D.T.D. 59A). A remarkable difference in the behavior of the two materials was at once apparent, as is seen in the extension-time curve shown in Fig. 1. Elektron A8 yielded continuously at a fast rate throughout the duration of the test, the magnesium-cerium alloy suffered no appreciable deformation after the first 50 hours. The curves given in this paper show the relationship between total strain and total time of exposure to the test temperature. This differs from the method often employed of plotting only the creep strain against time. The method of conducting these tests was such that no claims for a high degree of accuracy are made. Individual observations of strain are believed to be correct to less than 0.03 percent, and the values for the creep rate to be correct to about 2 x 10^{-6} in. per in. per hour.

A further comparative test using the same two materials was then made with a stress increased to 4 tons per sq inch. This test was terminated by the failure of Elektron A8 after about 48 hr at 200 C. Magnesium-cerium alloy remained unbroken, but showed an extension of 3.9 percent, Fig. 2.

Poor performance of Elektron A8 caused this material to be discarded. Subsequent tests of comparative nature were made using an aluminum alloy, "R.R. 50," of specification D.T.D. 133c. Creep tests at stresses of 3 and 4 tons per sq in. were made and the results are shown in Figs. 3 and 4.

The composition and mechanical properties of the various alloys used in the creep test referred to are given in Table V.

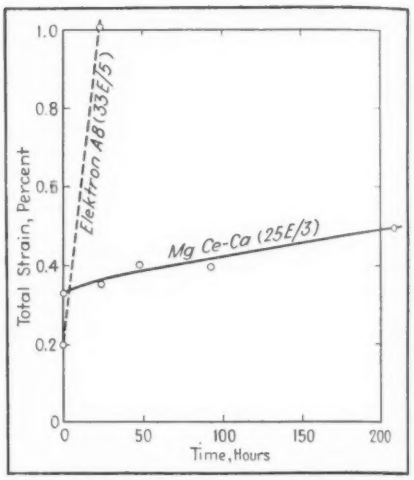


Fig. 2—Materials: Elektron A8 and magnesium +1.24 percent cerium +0.12 percent calcium. Stress: 3 tons per sq inch. Temperature: 200 C.

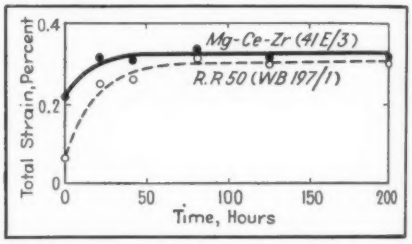


Fig. 3—Materials: Magnesium +2.67 percent cerium +0.4 percent zirconium and "R.R.50" aluminum alloy. Stress: 3 tons per sq inch. Temperature: 200 C.

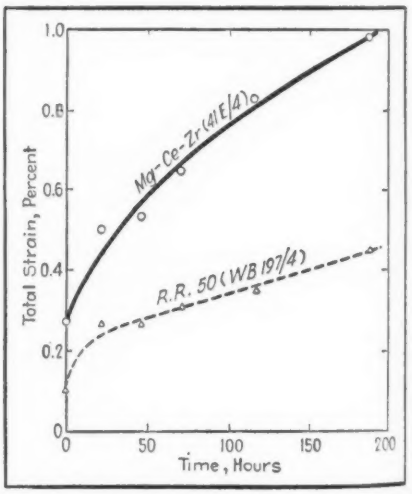


Fig. 4—Materials: Magnesium +2.67 percent cerium +0.4 percent zirconium and "R.R.50" aluminum alloy. Stress: 4 tons per sq inch. Temperature: 200 C.

In general no attempt was made to develop the maximum attainable hardness or to stabilize the material at test temperatures before commencing creep tests. Heat-treatment applied considerably affects the behavior of materials in a creep test. Therefore all the creep tests referred to above were checked

Table V—Composition and Mechanical Characteristics of Materials Used for Creep Tests (Sand-Cast D.T.D. Test Bars)

1. Experimental Magnesium Alloys

Creep Test Reference	Composition, Percent					Melt No.	0.1 Percent Proof Stress, tons per sq in.	Ultimate Tensile Strength, tons per sq in.	Elongation, Percent on 2 in.
	Ce	Zr	Ca	Ag	Zn				
Fig. 1.....	1.81	....	....	....	....	24E	....	....	....
Fig. 2.....	1.24	....	0.12*	....	....	25E	...	....	....
Figs. 3 and 4	2.67	0.40	....	....	....	41E	5.1 5.3	7.6 8.3	1.5 2.5
Figs. 11 and 12...	2.57	0.49	....	....	....	63E	6.1 6.2	10.7 10.2	6.0 5.5
Fig. 13.....	2.58	0.71	....	....	2.32	313	7.2 5.3	9.2 9.2	1.5 3.0
Fig. 14.....	....	0.55	....	3.12	....	69E	4.1 ...	11.6 13.5	11.0 13.0
Fig. 14.....	....	0.78	....	....	3.0	73E	5.8 6.1	14.8 14.0	13.5 9.0

* Nominal.

2. Standard Magnesium and Aluminum Alloys

Creep Test Reference	Alloy	Melt No.	0.1 Percent Proof Stress, tons per sq in.	Ultimate Tensile Strength, tons per sq in.	Elongation, Percent on 2 in.
Figs. 1 and 2.....	Elektron A8	....	5.2	10.5	2.5
	7.9 percent aluminum	33E	...	10.7	2.5
Fig. 3.....	"R.R.50"	WB. 197	5.7*	11.1	2.5
Fig. 4.....	"R.R.50"	WB. 197A	7.5	11.5	1.75†
Fig. 11.....	"R.R.50"	WB. 199	7.0	11.4	2.25
Fig. 12.....	"R.R.50"	WB. 264	7.1	12.2	2.0
			7.0	12.4	3.0

* Value for proof stress lower than usually obtained.
† Specification D.T.D. 133c requires a minimum elongation of 2 percent.

Table VI—Mechanical Properties of a Magnesium-Cerium-Zirconium Alloy

Composition: Cerium 2.57 percent, zirconium 0.49 percent, magnesium remainder. (Sand-cast D.T.D. test bars, tested at room temperature.)

Marks	0.1 Percent Stress, tons per sq in.	Ultimate Stress, tons per sq in.	Elongation, Percent
63E/1	6.1	10.7	6.0
63E/4	6.2	10.2	5.5

by uninterrupted tests carried out on a special creep test machine and the results confirmed the conclusions expressed in this paper.

Effect of Grain Refinement

Exploratory tests established that the new magnesium alloys had superior properties to magnesium alloys in general use. However, only the alloys containing zirconium possessed sufficiently good mechanical characteristics at ordinary temperatures to make the material practically useful. To develop these alloys further it was decided that the highest possible degree of grain refinement was required. It was appreciated that extreme grain refinement might be prejudicial to good creep resistance. For this reason creep tests were carried out parallel with a test at ordinary temperatures. Fine grained alloys showed improvement as indicated by Table VI and Fig. 5, showing creep test results.

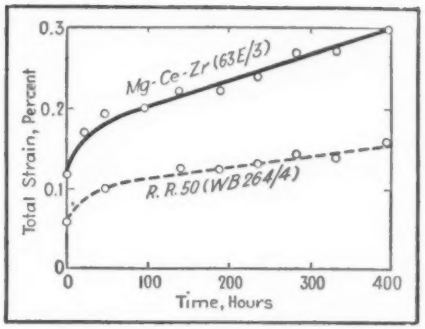


Fig. 5—Materials: Magnesium +2.57 percent cerium +0.49 percent zirconium and "R.R.50" alloy (both stabilized at 200 C) for 68 hours. Stress: 3 tons per sq inch. Temperature: 200 C.

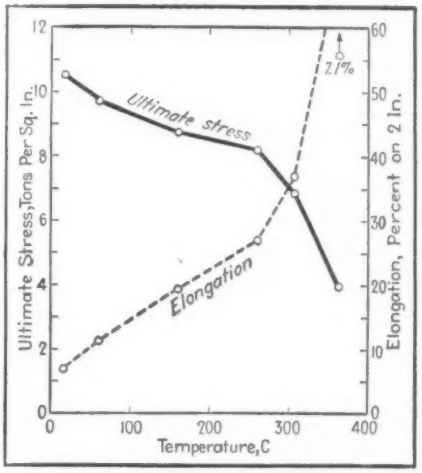


Fig. 6—Results of short-time tensile tests on a magnesium-cerium-zirconium alloy. Composition: Cerium, 2.99 percent, zirconium 0.65 percent, magnesium remainder.

Marked improvement over the original alloys is shown, particularly in the high proof stress and valuable ductility. In Fig. 6 the results of short-time tensile tests are given.

Variation of Mechanical Properties with Cerium Content

Test castings were made under carefully controlled conditions. Each melt was cast at 750 C. The values for the mechanical characteristics obtained in tensile tests at ordinary temperatures are given in Fig. 7. It will be noted that cerium does not have a marked effect on the ultimate stress of the material, but the proof stress increases steadily as does the Brinell hardness. Elongation decreases sharply. A study of this figure leads to the conclusion that the best combination of properties is possessed by alloys containing between 2.5 and 3.5 percent cerium.

Detailed tests were conducted to study the effect of zirconium content

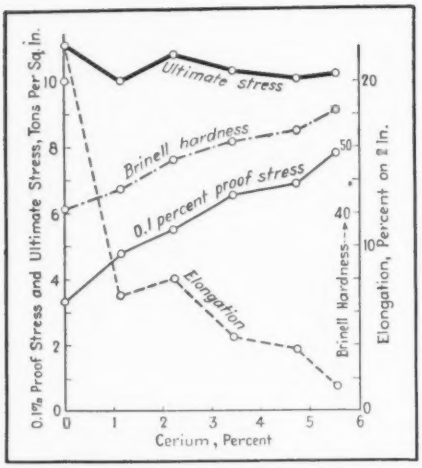


Fig. 7—Effect of cerium content on mechanical properties of magnesium alloys.

on response to heat-treatment. The previously discussed results were confirmed. Little was gained by heat-treating the specimens, either proof stress, ultimate stress or in hardness.

Conclusions

1. Magnesium-cerium alloys can be successfully cast in sand molds.

2. Mechanical properties of simple binary alloys at room temperature are poor. Results are apparently incapable of improvement either by superheating the metal before pouring or by heat-treatment of the castings.

3. Refinement of a structure obtained by the addition of zirconium leads to considerable increases in proof stress, ultimate strength and ductility of the alloys.

4. A good combination of properties is obtained with an alloy having about 3 percent cerium and 0.6 percent zirconium. This alloy shows values for proof stress, ultimate stress, and elongation on the same level as those of magnesium-aluminum series now in general use. Such alloys cast well, giving products of high order of soundness. The fine dispersed shrinkage met with in the magnesium-aluminum alloys has not been encountered in magnesium-cerium-zirconium alloys of the above composition.

5. Cast alloys containing cerium retain their strength well at elevated temperatures.

6. In creep tests carried out at 200 C the magnesium-cerium alloys with and without zirconium show great advantage when compared to the standard magnesium-aluminum alloy, Elektron A8.

7. Heat-treatment produces only minor modification to the mechanical properties of the magnesium-cerium-zirconium alloys.

Note: These tests were carried out by J. Stone & Co. Ltd., and assisted by Magnesium Elektron Ltd.

Zinc Alloy for Die-Casting

From "Die Casting Progress, Part II" by Dr. A. C. Street, *Metallurgia*, December 1947, Vol. 37, No. 18, page 67.

Zinc alloy die-casting uses could be easily found during the progress of a normal day in office, automobile, factory or home. It would be much more difficult to imagine a day in which such castings were not encountered.

After years of struggle against prejudice, the stage has been reached where most of the major users of die-castings are well aware of the properties of zinc alloys. They have much experience in designing their products to take full advantage of this material. The reason for any lingering prejudice is found in the early history of die-casting. When pressure die-casting began, low melting point and fluidity were the properties that determined which alloy was to be used. Lead and tin base alloys were chiefly used. Zinc alloys were developed subsequently to provide extra strength and, as they have melting points below 400 C, the pressure casting equipment of 25 years ago was able to cope with the material. At that time, however, the serious consequences of relatively small amounts of certain impurities were not appreciated, and there was still a tendency to add tin or lead to any alloy that required more fluidity when molten.

Until about 1924, a zinc alloy containing tin and copper was widely used. It die-cast well and had a tensile strength of over 10 tons per square inch. At about that time, a new zinc alloy was developed containing 4 percent aluminum and 3 percent copper. This had still greater strength than the older zinc alloys and it replaced them.

Die-castings in this new alloy were used for many purposes but the alloy was not free from defects of embrittlement, cracking and even of disintegration. It was proved, during the early 1920's, that the addition of a trace of magnesium reduced the inter-crystalline corrosion, which was the major defect. Then it was shown that zinc alloys were unreliable because of the presence of small amounts of tin, lead and cadmium.

By the early 1930's, British die-casters were using "four nines zinc" which was then commercially available. Based on zinc of this purity, an alloy with 4.1 percent magnesium was widely used. It did not disintegrate in service but its properties were still not completely satisfactory. On aging, its tensile strength and elongation were retained but its impact strength fell gradually; also, castings were subject to dimensional change.

Two copper-aluminum-magnesium-zinc alloys became available before the war, and in 1939 it was realized that one of these was superior for precision castings and stressed components. Because copper was virtually absent in this alloy, it was stable with respect to retention of mechanical properties and dimensions. Slight reduction of tensile strength and increase in percentage elongation were the most significant results of aging. This alloy also had good resistance to corrosion.

By 1938, the range of application of pressure die-castings was increased and various test specimens of ammunition components were die-cast and supplied for tests at the Royal Ordnance Factories. The castings were submitted to rough useage and filling tests; followed by full scale firing tests. These tests proved satisfactory and contracts were let for grenade fuse parts made by this process. When war was declared, designs for die-casting several ammunition components in zinc alloy had been approved and tested.

Early in 1941, the first British Standard Specifications for zinc die-casting alloys were issued. As shown in Tables I and II, these specifications covered compositions of two alloys and the die-castings produced from them. These specifications clearly show how undesirable elements, especially tin and cadmium, enter alloys during die-casting.

During the war, it was necessary to specify an alloy with lower standards or purity. This alloy was such that re-melted clean castings could be used as the ingot metal. It was thought this alloy would disappear after the war, but present short supplies have made necessary its continued use, especially for tags and other lightly stressed parts.

It is likely that most British die-casters will keep their production to alloy B.S. 1004/A until a better alloy becomes available. However, there is a steady demand for B.S. 1004/B

Table I—Chemical Composition Of Alloy Ingot Metal

Element	B.S. 1004/A	B.S. 1004/B
	Percentage	Percentage
Aluminum	3.9 –4.3	3.9 –4.3
Copper	0 –0.03	0.75–1.25
Magnesium	0.03–0.06	0.03–0.06
Iron	0 –0.075	0 –0.075
Lead	0 –0.003	0 –0.003
Cadmium	0 –0.003	0 –0.003
Tin	0 –0.001	0 –0.001
Zinc	Remainder	Remainder

Table II—Composition of Die-Castings In Zinc Base Alloys

Element	B.S. 1004/A	B.S. 1004/B
	Percentage	Percentage
Aluminum	3.9 –4.3	3.9 –4.3
Copper	0 –0.10	0.75–1.25
Magnesium	0.03–0.06	0.03–0.06
Iron	0 –0.10	0 –0.10
Lead	0 –0.005	0 –0.005
Cadmium	0 –0.005	0 –0.005
Tin	0 –0.002	0 –0.002
Zinc	Remainder	Remainder

because of its greater hardness and strength; in Switzerland, production appears to be concentrated on the latter alloy. British uses for B.S. 1004/B include toys and special gears.

Zinc alloy die-castings are not intended for continuous service at elevated temperatures. For a stressed component in alloy A, the temperature should not exceed 100 C. Alloy B castings should not be used at temperatures above normal since they are liable to slight reduction in impact strength on aging and that process is accelerated by heating.

Information is less exact concerning the effect of lowered temperatures. Reduction in temperature causes no marked deterioration in tensile strength, but impact strength is lowered. It must be appreciated that even at —40 C the impact strength of zinc alloy is still greater than that of ordinary cast iron, and is comparable with that of cast aluminum alloys at ordinary temperatures. On restoration of normal temperatures, the impact strength returns to normal.

Thermosetting Laminates

From "Evaluation of Thermoset Laminated Sheet Products," by Dr. F. L. Minnear, Shellmar Products Corp., presented at the annual meeting of the Low Pressure Industries Division, Society of the Plastics Industry, January 16, 1948.

THERMOSETTING LAMINATES consist essentially of two types of products: (1) High pressure laminates—these are the older, conventional products; and (2) contact pressure laminates.

The chemical nature of these two products is quite different. High pressure laminates are usually made with phenolic resins. The binder for phenolic laminates is the "condensation product" from the reaction of phenol and formaldehyde. To obtain the best characteristics in the completely cured resin and to avoid escape of gaseous products of the condensation reaction, great pressure is required during the molding operation. The reaction is irreversible.

The binder for contact pressure laminates is frequently termed a "polyester resin." Specifically, it is a copolymer of a vinyl compound, such as styrene, with an unsaturated alkyd made from a glycol and dibasic acids, In the presence of a peroxide catalyst, active copolymerization takes place on heating to form the thermoset resin. The reaction is exothermic, but there are no gaseous byproducts created; therefore, no pressure is required to obtain the best characteristics of the cured resin. This reaction, too, is irreversible.

A notable recent development in high presure laminates is the use of melamine-formaldehyde treated paper on the top of laminates to obtain greater surface hardness, higher heat resistance, reduced electrical tracking, and light-fast pastel colors for decorative use. Also, all-melamine laminates are now being made.

During the war resins and paper were developed for molding under reduced pressures, in order to utilize wood veneering processes. Thus, low-pressure phenolic laminates were developed. Molding pressures from about 50 to 400 psi were used. The product usually simulates the high-pressure laminates, but its electrical properties, water resistance and other properties, excepting strength, are considered somewhat inferior. Phenolic treated paper has been molded directly to surface wood, and even thin layers of wood have been impregnated and used as the surface. Other new reinforcing fillers, such as glass cloth and fiber have been used.

Phenolic resins cure to a dark brown color so that only dark colored laminates, such as browns and blacks, are possible. However, surfacing sheets of melamine treated filler are applied, to make colored decorative laminates. However, the product cannot be made transparent, although an all-melamine laminate can be made translucent.

One of the problems in this industry has always been to make perfectly flat sheets, without warping. In making melamine-surfaced phenolic laminates this problem is more aggravated.

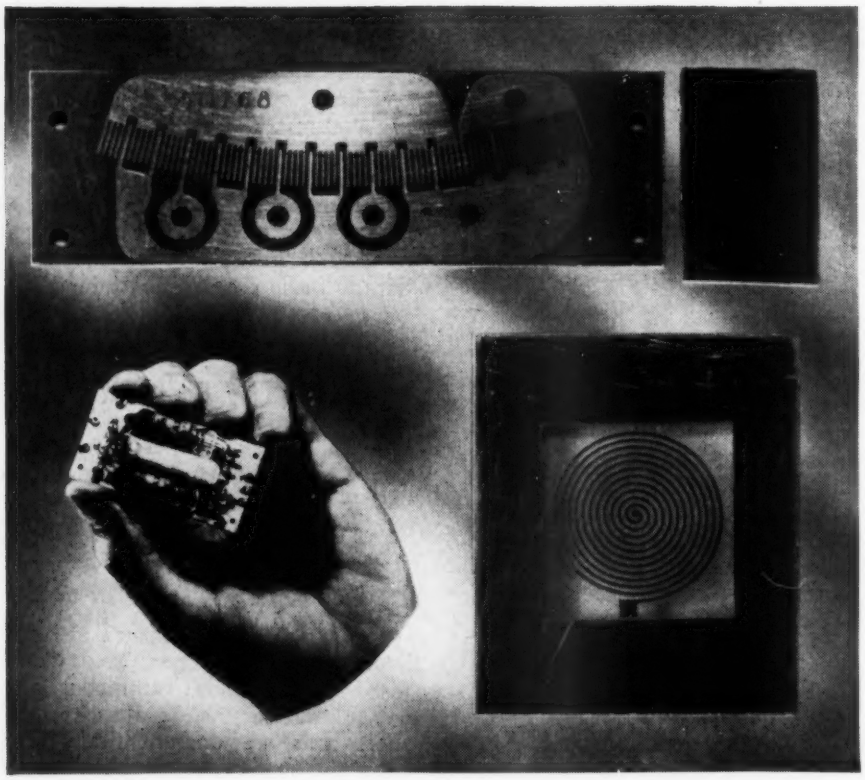
Melamine resin laminates are relatively high in cost. It costs nearly as much to make a 1/32 in. thick melamine-surfaced phenolic laminate as it does to make a 1/16 in. laminate, because the saving in thickness is obtained by using fewer of the less expensive phenolic treated layers. For the thinner laminates, therefore, the melamine surfaced phenolic laminates have a high raw material cost in addition to their high labor cost, compared with contact pressure laminates.

Phenolic laminates, as well as those containing melamine resin, are hard and rigid, and can be made in almost any thickness.

Contact pressure laminates are made by a continuous process. The greatest disadvantage of the continuous contact pressure laminating process is that short runs are uneconomical. The nature of the process makes it virtually impossible to "cross laminate" the treated fillers, but this is overcome, when necessary, by obtaining fillers which are of approximately equal strength in both directions.

Polyester resins cure to a transparent, almost colorless solid; there is no difficulty in obtaining any color or shade. Any design that can be printed is possible. A high degree of translucency is obtainable. When opacity is desired, opaque pigments are incorporated in the fillers or in the resin. Because the laminate is cured without pressure and strains are not set up, there is practically no warping of the laminate.

Although polyester resin laminates can be made over one inch in thickness, the continuous process as now performed does not lend itself to making thicknesses greater than about 0.1 in. The principal reasons for this limitation are: (1) Slow speed of curing—the exothermic heat generated during the polymerization reaction is dissipated much more rapidly in the thinner sheets; and (2) weight of the webs in thicknesses over $\frac{1}{8}$ in. may cause sagging of the laminate during the curing operation, resulting in a "bowed" sheet. However, thicknesses of 1/16 in. down to 0.005 in. are ideal for the continuous contact pressure laminating process.



PRINTED CIRCUIT TECHNIQUES produced the Centralab miniature audio-amplifier held in the hand above. Three other units made by photosensitive printing processes.

Industry Evaluates Printed Circuits

Circuit conductors can be printed by a number of methods and have proved valuable in making compact electronic units with very small auxiliaries.

PRINTED ELECTRONIC CIRCUITS are no longer in the experimental stage. Introduced into mass production early in 1945, in the radio proximity fuze developed by the National Bureau of Standards, printed circuits are now the subject of intense interest of manufacturers and research laboratories. The first large scale production was done by the Centralab Div. of Globe-Union, Inc., (see PRODUCT ENGINEERING, July 1946, p. 134) and they have continued with research into methods and applications.

Now actively being developed by various laboratories are printed circuits for electronic controls using gas-filled tubes, electronic units for hearing aids, I. F. strips for radar and UHF equipment, subminiature portable radio transceivers, and electronic circuits for business machines, switching and recording equipment. Other applications includes antennas, interstage coupling units, microwave components, shields and the printing of graphs with conducting lines over which contacting arms move to select answers to functions of one or more independent variables.

Standard electronic components are now available in such miniature size that complete amplifiers can be built into volumes of less than 1 cu in. By providing thinner base materials, or by applying the wiring to an insulated outer or inner surface already present in the assembly, such as the tube envelopes or parts of plastic cabinets, significant reduction in wiring volume can be achieved. Development of truly diminutive electronic devices now awaits only the availability of smaller microphones, transformers, speakers, batteries and tubes.

There are six main classifications into which techniques for printing circuits fall: Painting, spraying, chemical deposition, vacuum processes, die-stamping and dusting. Some of the processes are new, some have been used for years and others have not been applied to production but point the way to new techniques. The processes differ mainly in the manner in which the conductors are produced. Resistors and capacitors are applied by methods that in general may be used interchangeably with any of the processes. In this country, considerable interest is being displayed in the painting, spraying and die-stamping methods. Since all these processes reproduce a circuit on a surface, they are classed generally as printed circuits.

The practice is only adaptable to conductors, resistors, capacitors, inductors, shields, and antennas. By printing the circuit on a base plate of high dielectric constant, capacitors, wiring and inductors can be printed in a single operation. Complete circuits can be printed on cylinders as well as flat surfaces.

The most practical way to increase the conductance of printed elements is to electroplate over the initial printing. A good rule is to print a thin layer of the order of 0.0005 in. or less and to electroplate on top of this. Copper plating on silver is practical for increasing the conductance, using an ordinary acid-copper sulphate bath. Best results are obtained if the initial layer is plated at low current density; about a deposition rate of 0.0005 in. per hour for the first ten minutes. A procedure followed in increasing the thickness of the coating is first to plate the initial silver layer with copper and then add a final silver coating over the copper. This facilitates soft soldering direct to the leads. Dip-soldering techniques can also be used.

Other metals can be plated directly on the silver if desired. Good results are obtained by dipping the printed plate into a dilute sulphuric acid bath and rinsing with water before plating. Materials in the plating bath should be selected so as not to attack the base material or paint constituents.

Protection against abrasion, humidity and other effects is obtained by applying special resin coatings over the resistors. Baking the coating produces a scratch-proof as well as humidity-proof envelope. It also renders the resistors more stable against the effects of temperature cycling.

A two-stage amplifier has been painted on the envelope of a miniature 6J6 tube. This is a complete unit requiring only plugging into a

power supply to operate. Lead wires from the circuit to the tube prongs are painted on with a brush.

In designing a printed circuit, when it is impossible to avoid lead wire crossovers, they can be separated by a thin insulating lacquer coating.

Replacement of defective printed subassemblies in an installation introduces new possibilities in manufacture and maintenance. Principal units of the set can be made as plug-in subassemblies and can be removed, tested and replaced in the same manner as tubes. Some of the subassemblies already made have been encased in a special casting resin (PRODUCT ENGINEERING, page 159, August 1947) to protect them against manual and atmospheric abuse.

A novel application of the printed circuit principle has been in its use as electromechanical strain gages. These may be made by applying a layer of resistance paint to the surface under study and measuring the change in resistance as the member is stressed.

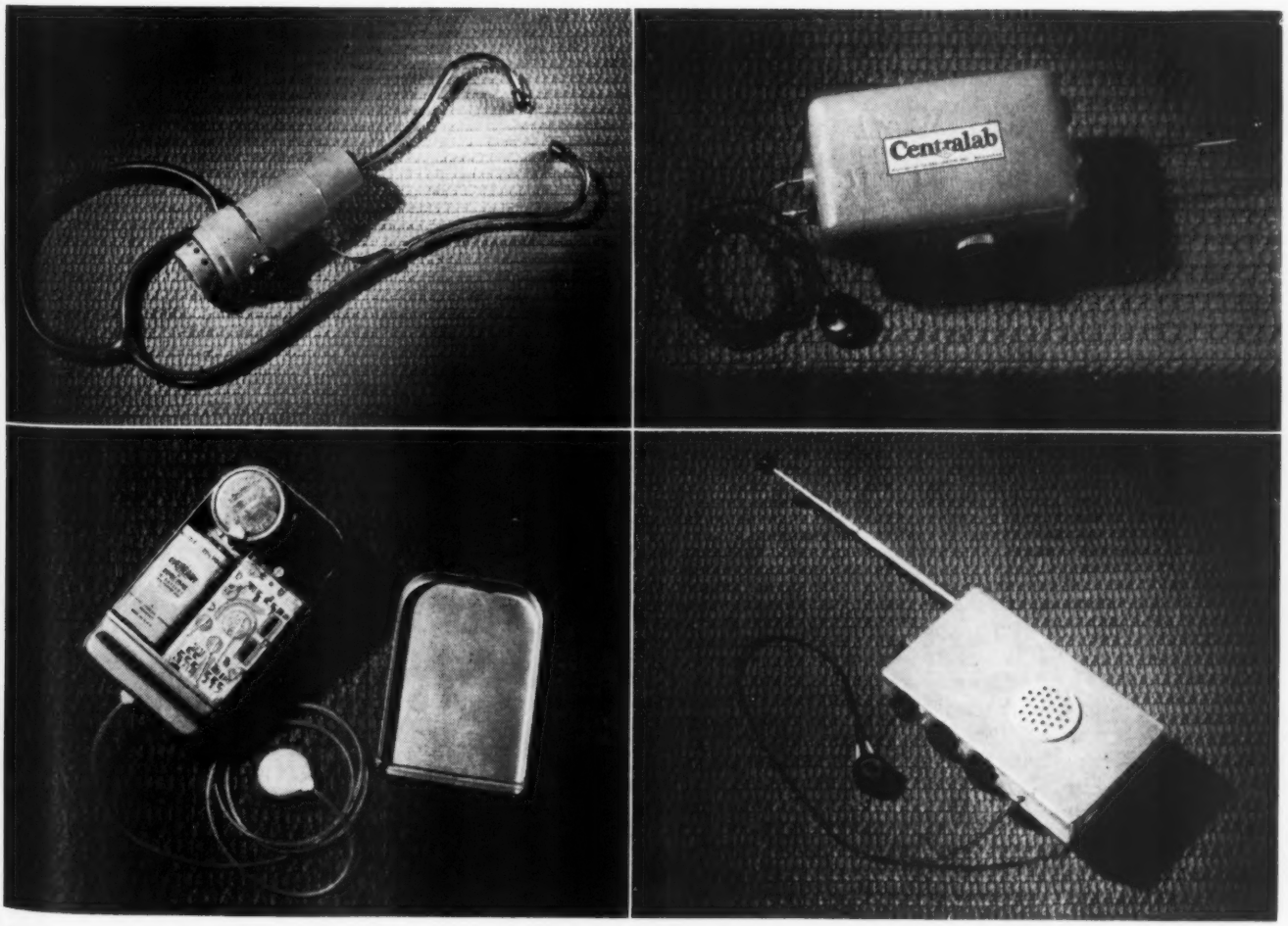
The same technique was used in the manufacture of a lightweight phonograph pick-up. It consists of a flexible cantilever beam $\frac{1}{2}$ in. long and approximately 0.06 in. square made of polystyrene. The needle is permanently attached to one end. The other end is anchored to the tone arm. A thin resistance layer is painted on the side of the beam. It runs out to the free end of the beam on the top half of the side and returns on the bottom half in horizontal U-shape manner. Lateral displacement of the needle as it rides over the record, flexes the beam and produces a proportional variation in resistance of the layer. A voltage change proportional to the variation in the resistance is fed to the amplifier.

This unit was particularly interesting in that pick-up was free of hiss or background noise.

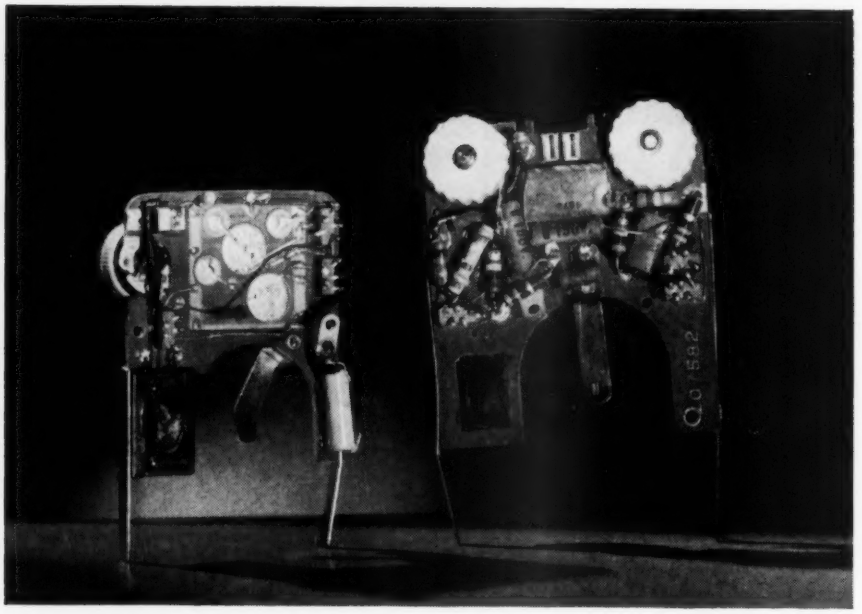
The status of patents on printed circuit techniques is one that cannot be stated in explicit terms. Many of the techniques are adaptations of processes patented long ago. Much of the technical information is classed as standard knowledge of the art and is unpatentable. Patents have been applied for by industrial organizations and by the government but the present back-log of work in the patent office (page 163, this issue) prohibits an early decision on patent applications.

It is thought that most of the patents in process relate principally to specific and perhaps limited processes and applications. Patents applied for by the government may ultimately be made available to industry on a non-exclusive basis without charge. Concerns planning to use printed circuits commercially are advised to check the patent situation in the same manner as would be employed in adapting any new manufacturing process.

The principal item requiring further attention to achieve over-all perfection in printing circuits is the development of improved methods of printing resistors. Although much is known about printing resistors, and values have been printed in large scale production covering almost the entire range needed in modern electronic manufacturing, much remains to be learned about resistor manufacture before all of the extensive requirements imposed on them by their use in modern electronic sets can be met satisfactorily. Even here the present status is good. Mass production lines have been



PRINTED CIRCUITS are used to reduce size in all types of portable equipment: (upper left) American Medical Instrument & Supply Corp. electronic stethoscope, (upper right) signal tracer, (lower left) Allen-Howe Electronics Corp. hearing aid and (lower right) transceiver.



PRINTED ELECTRONIC CIRCUITS are constantly being refined. Illustrative of progress being made is Centralab's 1948 hearing air, left compared with the much larger 1947 model.

set up and are producing printed circuits in their entirety at the rate of thousands per day.

A manufacturer does not, however, need to set up his plant to produce sets that are printed in every electronic detail to take advantage of printed circuits. Some have introduced the novel process by printing only a subassembly or an interstage network of a complex set. Some have printed only the conductors, and have used standard resistors and capacitors for the remainder of the circuit. In this case, the methods usually employed to date have been painting, spraying and cold die-stamping. Hundreds of thousands of electronic sets of all types have been produced in this country and abroad utilizing these techniques in one or more subassemblies. Printing circuit conductors and using standard resistors and capacitors has proven an attractive way of adopting printed circuit practice with a minimum of changeover.

Quality Control is Concern of Product Designer

Two Day Statistical Methods Course Offered as Practical Guide to Parts Buyers

RECOGNIZING A VITAL but much misunderstood branch of engineering, a free two-day course on controlling quality of manufactured parts, to be repeated weekly, will be inaugurated by the Hunter Pressed Steel Company, Lansdale, Pa., on April 6. Because modern statistical methods for controlling the quality of manufactured parts, and inspecting purchased parts, hold such far-reaching benefits for component-buying industries—yet are so little understood and practiced—the course has been planned for inspectors as well as purchasing agents and product designers.

The course will take two full days (Tuesday and Wednesday of each week), involve seven lectures by specialists in the field, one forum-type discussion, a complete plant tour to demonstrate Hunter's own quality control methods, and a full afternoon of actual testing and calculating practice in using the principles learned. The course will be given in Lansdale, and the only expenses involved will be living and traveling costs.

Although Hunter manufactures springs, and springs will be used as the sample products throughout the course, the methods and interpretations taught will have application in all industries. Philip C. Clarke, who is in charge of the course, is an active proponent of the industrial application of statistical methods, and has been pioneering in the field since 1932.

An interesting part of the course will be actual work with several new testing machines and instruments which have just recently been developed for the exact measurement of important characteristics of the notoriously hard-to-measure coil springs. It is expected that such instruments soon will come into widespread use.

Management men who are involved in purchasing or inspection functions are invited to correspond with Hunter regarding particulars of the course and the possible assignment of men to take it. Ten men can be enrolled at a time, and it is urged that all men from a given company come in a group. The topic is considered of sufficient significance that the course will be continued until all qualified enrollees will have been processed—even if it takes five years.

Topics to be covered will include: Use of the frequency-distribution curve and the correlation chart in inspection for analysis of production troubles; production control charts; out-going sampling techniques; quality reports; types of defects; causes and detection; sampling; 100 percent testing; load-testing of springs; pressureless measurement of flexible parts; gaging; supplier reports; lot-to-lot variation; non-normal distribution; spring specifications and their interpretation; electronic instrumentation; standard forms and reporting techniques; demonstrations of all types of commercial load-testing apparatus for flexible parts; and the use of the standard f-d curve.

Here is the agenda of the course:

Tuesday am
- 8:30-9:00, preliminaries
- 9:00-12:00, plant tour

Tuesday pm
- 1:00-5:00, "Spring Inspection", demonstrations
- 7:00-8:30, "Inspection Technique", lecture
- 8:30-9:30, forum and discussion

Wednesday am
- 8:00-9:00, "Spring Specification", lecture
- 9:00-10:00 "Sampling and Reporting", lecture
- 10:00-11:00, "Load Testing of Springs", lecture and demonstration
- 11:00-12:00, "The New 217-P Tester", demonstration

Wednesday pm
- 1:00-4:30, "Testing Practice", laboratory.

Washington Notes

Second Session 80th Congress To Decide Major Legislation

The first session of the 80th Congress left many controversial bills on the calendar when it adjourned. Bills with extreme national and international significance demanded attention and caused delay on other scheduled legislation. Many of the resolutions and acts now under consideration will also require policy decisions at high levels.

SYNTHETIC RUBBER. Congress is working out the last details of a permanent peacetime synthetic rubber program. The provisions of the Shafer bill, product of the Republican House Armed Services Committee, seemed most likely to prevail—although a counter-bill sponsored by Republican Senator John Bricker, of Ohio, may carry some of its points.

In general, the Shafer bill, which is backed by the Administration, smaller rubber manufacturers, and big users of rubber products but violently opposed by at least one large producer, does the following:

It authorizes a rubber agency with authority to enforce product specifications, allocations, and inventories of both chemical and natural rubber.

It practically prohibits disposal of the government's plants; in fact, it declares that there is no reason why the plants should be disposed of.

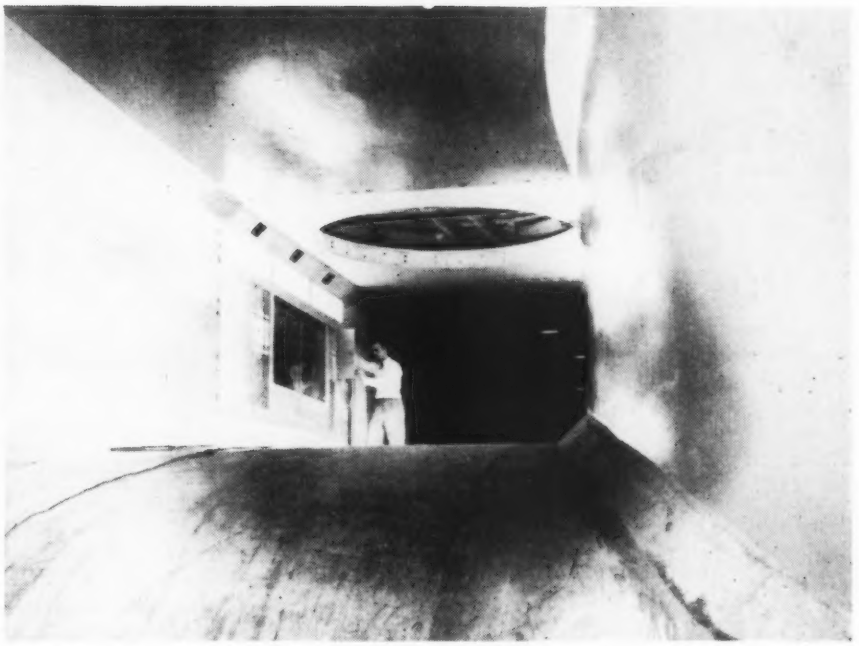
It emphasizes that national security is the paramount consideration and until the rubber industry itself provides synthetic rubber production of sufficient magnitude, the government must remain a major factor. To this end, the bill specifically provides for keeping the government plants technologically up-to-date.

The Bricker bill, on the other hand, lays emphasis on need for stimulating a private synthetic industry, and to that end makes easier the sale or lease of government rubber plants to private industry. The bill is supported in general by the major rubber companies, although they differ on details.

The outcome seems most likely to favor the Shafer proposals: Congress is security-minded, and the Shafer arguments on security will likely override the Bricker arguments about getting the government out of the rubber industry.

SYNTHETIC FUELS. Whether to build and how to build a synthetic liquid fuels industry is one of the hottest subjects currently on the agenda. The basis on which such a program is contemplated—national security—is assurance that the idea will be fought back and forth for many months. There's little likelihood that anything can be done or would be done immediately—too many severe shortages of equipment and materials, already exist. Secretary Krug isn't going to push for immediate action. In February he got about all the Interior Department could expect at this time, which was Congressional approval of an extension of the present Interior synthetic fuels program until April, 1953. At the same time, an increase in appropriations of 30 million dollars was authorized, bringing the total for the program up to 60 million dollars.

Meantime, the industry contemplates the significance of such proposed legislation as the Wolverton bill (HR 5475) which states that it is the policy of the United States to "promote the production of synthetic liquid fuels, and to that end to facilitate the construction and operation by private industry of synthetic liquid fuel plants". The bill would authorize an appropriation of 400 million dollars and construction of three types of plants, each with a capacity of at least 10,000 barrels a day: Coal hydrogenation, synthetic gas from coal, and shale oil from oil shale. If private industry wouldn't undertake the construction with loans from RFC, then RFC



SUBSONIC AIRPLANE INVESTIGATION has been implemented by completion of a new wind tunnel at the Glenn L. Martin College of Engineering and Aeronautical Sciences, University of Maryland. While not the largest in size or wind velocities, the tunnel is among the most modern in the country and is equipped with every possible scientific aid to make wind tunnel tests, observe and calculate results and make photographs. A completely equipped woodworking shop is capable of making models to order and changing models brought to the tunnel for test purposes.

Housed in a concrete building with walls varying from one to three feet in thickness, the tunnel is rectangular in shape. The long sides are 166 ft in length and the short sides 70 feet. The tunnel varies in diameter from a maximum of 31 feet to a minimum of 7 ft 9 in.; narrowest dimension being in working section where models are studied, see picture.

Air force is supplied by a seven-blade propeller with a maximum of 850 rpm, producing velocities of 350 mph. Electric motors with a capacity of 2,250 hp are required at peak load.

Lights have been built into walls of the working section so that every movement of the test model can be observed and photographed. Observation is through a big glass window that makes one wall of the test section.

The facilities of the tunnel will be open to government and private industry without restriction.

is authorized to build and operate the plants.

The Senate Committee on Interior and Insular Affairs recently approved the Robertson bill. The bill, which would authorize construction of a lignite research laboratory, was passed by the House last July. The measure, which now goes to the Senate, would authorize expenditure of 750,000 dollars to build a laboratory for research into commercial use of lignite as a liquid fuel, for gasification, and for development of byproducts. It also provides for an expenditure of 250,000 dollars yearly for operation of the project.

SCIENCE FOUNDATION. A combined Science Foundation bill looks as though it has about the same chance of getting through Congress this year as last year's bill did at this time in the session. However, there's now almost universal agreement on the point that brought the President's veto last year: The question of presidential appointment of the director of the Foundation. Senator Smith and Congressman Wolverton have gotten together with Presidential assistant John Steelman—and the scientists are also reconciled to having the President name the executive authority of the Foundation. Hence there's nothing substantial blocking passage of a bill this year except one thing: It's not "must" legislation, and politically it could be held over until next year. This year's bill would be almost identical with the bill that got vetoed last year except for the placement of the power of appointment of the director. Brief hearings are likely; thereafter it becomes a question of getting a green light from the Republicans who control legislative traffic.

The Priest bill (H.R. 4852) is a rewrite of the vetoed Smith bill and will be pushed aside when the Republicans come up with a new Smith-Wolverton version of the Science Foundation bill.

OFFICE OF TECHNICAL SERVICES. The Fulbright bill gives statutory standing to the Office of Technical Services in the Commerce Department, which provides service and information to inventors. It was reported out by a Senate committee on June 27, 1947, and nothing has happened to it since and probably won't unless Representative Taber decides to cut off appropriations for OTS. If that happens, then the bill probably will be pushed through. Actually the office is being operated illegally but as long as it can get its appropriation there will be no effort to enact the Fulbright measure.

Foreign Reports from McGraw-Hill World News

Patent Reciprocity Act Not Passed in Australia

Unlike New Zealand, Australia has not passed legislation to provide for reciprocity under the Boykin Act, nor is Australia yet a party to the Neuchatel agreement.

This places both American and Australian wartime inventors at a great disadvantage as far as reciprocal protection under belated applications is concerned.

However, a bill is likely to be passed by the Commonwealth Parliament to extend the provisions of the National Security (Industrial Property) Regulations and War Powers Act for a further twelve months. The Commonwealth Patent Office will therefore be able to continue granting various types of extensions which may partly overcome the disabilities arising from Australia's non-adherence to the Boykin and Neuchatel plans. If it can be proved that the lapse of the statutory term was caused by war conditions, an extension may be granted in regard to the filing and prosecution of applications for patents and other industrial property rights.

Under Australia's amended Patent Law, in operation since January 1, 1947, patent specifications are open for inspection almost immediately after filing, and without previous examination. An official of the Commonwealth Patent Office at Canberra told McGraw-Hill World News that he believes Australia to be the only country in the world which thus deals with new applications.

By subscribing to Australian patent abstracts, American corporations therefore have an opportunity of keeping abreast of competitive American inventive activities in cases where coverage is sought in the Commonwealth. In most cases an analogous abridgment may not appear in the U. S. Journal of Patents until many months later.

Outdated Indian Patent System Shown by Survey

British and American individuals and companies filed 1,800 of the 2,610 patents licensed by the Indian Controller of Patents during 1946, according to a survey recently made by that office. In the same year only 266 patents originated with Indian nationals.

Comparing the operation of the Indian patent system to that of "a 100 hp engine producing only 1 hp of work, 90 percent of which is for the benefit of aliens" the Controller criticizes the lack of patent-mindedness in India. He assailed the willingness to take up foreign methods and patents instead of developing new ones to meet India's needs.

The survey shows that Britain was the top patentee during the year, filing 1,348. Major role in this was played by Standard Telephone and Cables Ltd. with 233, followed by Imperial Chemical Industries Ltd. with 84. Among America's patentee's were General Electric with 65, and duPont with 60.

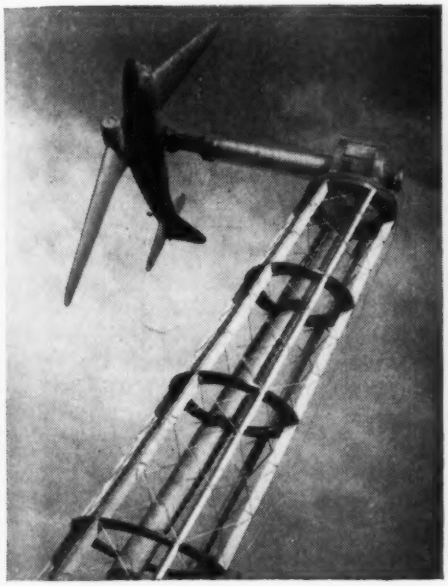
Among the Indian patentees were Tata Iron and Steel Ltd. with 12 and the Council of Scientific and Industrial Research with 27.

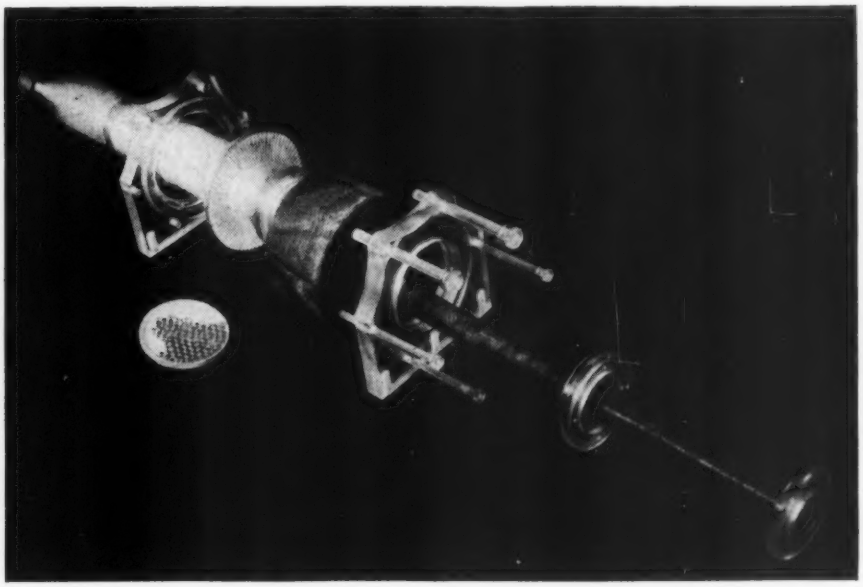
Machine Tool Show To Be Held in London

The International Machine Tool and Engineering Exhibition, sponsored by the Machine Tool Trades Association, Victoria House, Southampton Row, London, W. C. 1, will be held at Olympia, London, August 26 to September 11, 1948.

Seaweed—New Base for Packaging Materials

Seaweed was the raw material for a greenish fabric shown at the first Scottish Seaweed Research Association exhibition. It can be used to make plastics and clear papers.





Assembly Constructed of Plastic Parts

MORE THAN 25 PRECISION-MACHINED PLASTIC parts have been assembled into a new tower head for an aircraft antenna pattern plotter. Made by Airborne Instruments Laboratory, Inc., Mineola, N. Y., the plastic parts were fabricated from General Electric's cast modified polystyrene, with high electrical qualities.

The tower head is designed to rotate a scale model airplane in a high frequency radio field so the transmitter's signal can be received and recorded as a function of rotation.

Illustrated in right-hand picture are drive gears, bolts, ball bearings and formed parts made of modified polystyrene. Universal joint, ball races, screws and formed plates are also made of this plastic that increases test accuracy because plastics with high dielectric constant do not greatly affect test measurements.

Model movement is transmitted from vertical power shaft by universal joint operating a bevel gear set. As depicted in left-hand illustration, universal joint is pin-connected to driving bevel gear, which rotates in plastic bearing races.

Although no cold flow tendency has been noticed in these thermoplastic parts some physical limitations have been encountered. Threads on small bolts and screws, and on the end of interior draw-up rod have chipped and stripped under continued use. The hand knob on the draw-up rod shattered like glass when rod was dropped to the floor.

It was also found that plastic parts of this tower head should be assembled without using tools. When more than finger tension is applied, threads are liable to be stripped. However, advantages gained by good electrical properties offset assembly difficulties.

Overloaded Patent Office Make War Developments Unusable

TWO YEARS and 150,000 cases behind, the United States Patent Office is still acting on some applications originally filed during 1943. Among applications that have not received final action, are those for developments brought about by wartime research activity.

Present condition of the Patent Office has been brewing since 1943—when new patent applications reached a low point. There was a backlog of 39,000 cases at start of 1943 and 44,000 new applications were received during the year. Through efforts of 400 experienced examiners, backlog carried to 1944 was reduced by 5,000 cases.

Seven outstanding factors then combined to lengthen from two years to four years the average time for final disposition of each application.

1. Overcrowding of facilities. Examination of patent applications is work that requires intense concentration. At present, 40 percent more personnel occupy 20 percent less space than before the war.

2. Inexperienced examiners. Ninety percent of 1941 examining corps had continuous Patent Office service over five years. Today, 40 percent of examiners have less than two years' service.

3. Increasing volume of literature to be searched. Technical publications, texts and handbooks, upon which examiners must rely for knowledge of the arts, multiply rapidly. This lengthens time of search, as does increase in total number of patents granted. Patents outstanding increase about 20 percent every ten years.

4. Increasing complexity of cases. Closely related to preceding factor is complexity of new systems using theories, methods, functions and arrangements impossible to search by scanning drawings, and difficult to examine as applications.

5. Contraction of examining corps. Examiners become experts in concentrated fields of knowledge. When nearly a quarter of these specialists were lost during war period, the remaining force had to take over their work. This caused lowered output because examiners had to read extensively and proceed cautiously to avoid mistakes in unfamiliar fields.

6. High proportion of new cases in work load. Average applications are acted on three times before being allowed or rejected. Initial actions require more time than final actions. When ratio of new cases to old is

large, the total final actions completed by each examiner falls off.

7. Rising importance of validity. The duty of the Patent Office is to issue valid patents. By inference, its corollary duty is to refuse invalid patents. During periods of large backlog in the past, examiners have been pushed to increase output. This increases number of patents held invalid by courts and reduces confidence in the patent system.

Output per examiner has been lowered from nine to seven final actions per week as a result of these factors. However, since new applications have increased to double the 1943 yearly rate, the number of cases ready for final action is increasing and output will correspondingly increase.

With all the temporary and permanent factors working against it, there is talk that the present patent system may be abandoned in favor of a system of registration. Patent Office employees feel that this would be a grave error because an adequate, trained staff in Washington could maintain the integrity of patents and do so at a lower cost to the country.

The future outlook for the Patent Office is more hopeful than might be expected. Two hundred and fifty new examiners, scientists and engineers untrained in patents or law, have been added to the staff and are already carrying enough load to keep backlog from becoming larger. Experienced examiners must spend some time training new men, so, as the new men gain experience, output will jump.

When space becomes available, the Patent Office will increase its staff to the authorized 900 examiners. This is 100 more than needed to carry current load and will reduce backlog rapidly. At the same time, the wave of new applications in 1945, 46 and 47 will be advancing toward less time-consuming final actions. Optimistic Patent Office workers feel the backlog can be greatly reduced by the end of 1950 and that patents can then again be granted in about two years' time.

Fastest Motion Pictures Ever Made

FIRST FILM STRIPS made by world's fastest motion picture camera (PRODUCT ENGINEERING, March 1948, page 161) show research possibilities of high speed photography. Subject for these pictures is a .22 caliber bullet passing through a 2 mm pane of glass at a velocity of approximately 1,700 ft per second.

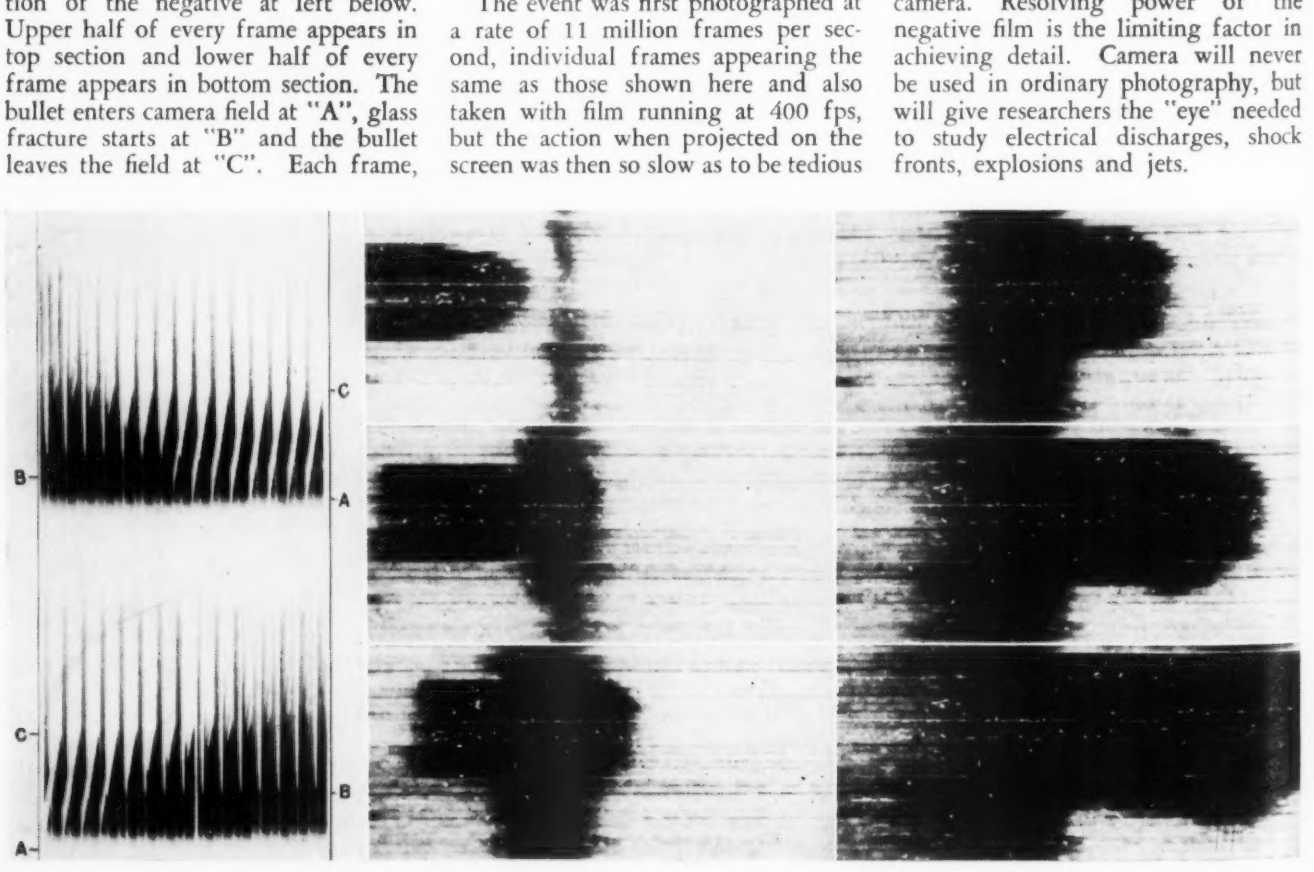
Two thousand dissected motion picture frames, taken at rate of 5 million per sec, are included in the reproduction of the negative at left below. Upper half of every frame appears in top section and lower half of every frame appears in bottom section. The bullet enters camera field at "A", glass fracture starts at "B" and the bullet leaves the field at "C". Each frame, as it appears on the film, is 1/2,500 in. high and 1 in. wide.

From studies of these pictures, it was learned that the glass fracture wave travels at a speed three times that of the bullet.

The negative image sections are returned to their original relationship by using the camera's optical system in reverse. Slow motion pictures are recorded from this system with an ordinary 16 mm camera.

The event was first photographed at a rate of 11 million frames per second, individual frames appearing the same as those shown here and also taken with film running at 400 fps, but the action when projected on the screen was then so slow as to be tedious to watch. The actual bullet is about one-half inch in length. The complete action was photographed in the flash from a FT-524 lamp that lasts for only 1/2,500 second, but running time for the slow motion action on the screen is two minutes. Prints were reproduced at intervals of approximately 40 frames or 8 microseconds.

Prints shown at right are selected at random from oriented film and illustrate detail that is possible with this camera. Resolving power of the negative film is the limiting factor in achieving detail. Camera will never be used in ordinary photography, but will give researchers the "eye" needed to study electrical discharges, shock fronts, explosions and jets.



Audio Engineering Society Organized

TO DISSEMINATE INFORMATION and to promote intelligent study of problems pertaining to audio engineering, the Audio Engineering Society was formed in New York City on February 17, 1948. It is a society sponsored by well known men actively engaged in the field and not by a commercial group or engineering society.

At the organizational meeting, Norman C. Pickering stated that audio subjects were treated on fringes of three established societies, but continued that audio engineers needed a common meeting ground of their own. Without an audio society, publication of information had a time lag of 1 to 1½ years. This has contributed to the slow advancement in audio work. Research was carried on, but each group had to make the same mistakes and learn the same facts independently.

Audio engineering has broadened and many phases should have greater recognition. It is hoped this new society will bring attention to such activities as: Speech input system design, studio design and use, disc, tape and wire recording, hearing aids, public address and telephone systems.

Aims of the Audio Engineering Society include:

1. Develop technical and public appreciation of the importance of audio engineering as a separate profession, with its own distinct background requirements.
2. Foster educational presentation of subjects basic to audio engineering.
3. Foster research on subjects basic to audio engineering.
4. Foster periodic audio engineering meetings.
5. Provide a facility for publication of papers on audio engineering.
6. Represent audio interests in the matter of engineering standards before the ASA, FCC, RMA and others of like nature.
7. Operate an employment register for qualified audio engineers.

Until the society writes a constitution and holds elections, the organizing executive committee: J. D. Colvin; C. J. LeBel; C. G. McProud; N. C. Pickering, Acting Secretary; C. A. Rackey; and R. H. Schlegel, Acting Treasurer, will continue operation of society affairs.

First technical meeting was held on March 11, 1948, at which Dr. H. F. Olson, RCA Laboratories, discussed high fidelity reproduction.

AIME Elects New President

William Embry Wrather, Director, United States Geological Survey was inducted as president of the American Institute of Mining and Metallurgical Engineers during their 1948 meeting.

Highlighted at this meeting, the 166th of the society, were papers presented before the Institute of Metals Division. Robert Steinitz discussed magnetic properties, especially permeability, of soft iron-powder compacts and indicated that raw material has little effect on properties compared for identical density parts and not for identical processing procedures.

Controlled porosity of powdered metal parts was subject presented by Pol Duwez and Howard E. Martens. They concluded that designers will specify metals to suit designs and not make designs fit existing powders.

Lively discussion followed presentation of a paper on nickel steels by powder metallurgy prepared by Laurence Delisle and Walter V. Knopp. The meeting showed interest in this initial investigation into combining metal powders to produce alloys.

Molding, coining and sintering properties of iron powder were evaluated by Jerome F. Kuzmick. He showed that increasing use of powdered metal parts has made powder suppliers more conscious of characteristics of the powders they make.

Since many men interested in powder metallurgy were gathering in New York for the AIME meeting, Stevens Institute of Technology chose this time to make their annual powder metallurgy medal award. This year the medal was presented to A. J. Langhammer, President, Amplex Division of Chrysler Corp., for his outstanding achievement in development and use of powdered metallurgy in bearings and machine parts.

MEETINGS

April 5-8

NATIONAL ASSOCIATION OF CORROSION ENGINEERS—Annual Conference and Exhibition, Jefferson Hotel, St. Louis, Mo.

SOUTHERN MACHINERY AND METALS EXPOSITION—Annual Meeting and Exhibition, Atlanta Municipal Auditorium, Atlanta, Ga.

April 13-15

SOCIETY OF AUTOMOTIVE ENGINEERS—Aeronautic and Air Transport Division Meeting, Hotel New Yorker, New York, N. Y.

April 15-16

AMERICAN ZINC INSTITUTE—Annual Meeting, Hotel Statler, St. Louis.

METAL POWDER ASSOCIATION—Annual Spring Meeting, Drake Hotel, Chicago, Ill.

April 19-21

AMERICAN SOCIETY OF LUBRICATION ENGINEERS—Annual Convention and Exhibit, Hotel Statler, Buffalo, N. Y.

April 19-23

AMERICAN CHEMICAL SOCIETY—Annual National Meeting, Headquarters: Stevens Hotel, Chicago, Ill.

April 22-23

WESTINGHOUSE MACHINE, TOOL ELECTRIFICATION FORUM—Hotel Statler, Niagara Room; second day at Westinghouse plant, Buffalo, N. Y.

April 26-29

AMERICAN MANAGEMENT ASSOCIATION—Annual Conference and Packaging Exposition, Public Auditorium, Cleveland, Ohio.

May 3-5

INDUSTRIAL FURNACE MFG. ASSOCIATION — Annual Meeting, The Homestead, Hot Springs, Va.

May 3-7

AMERICAN FOUNDRYMEN'S ASSOCIATION—Annual Meeting, Phila.

May 3-14

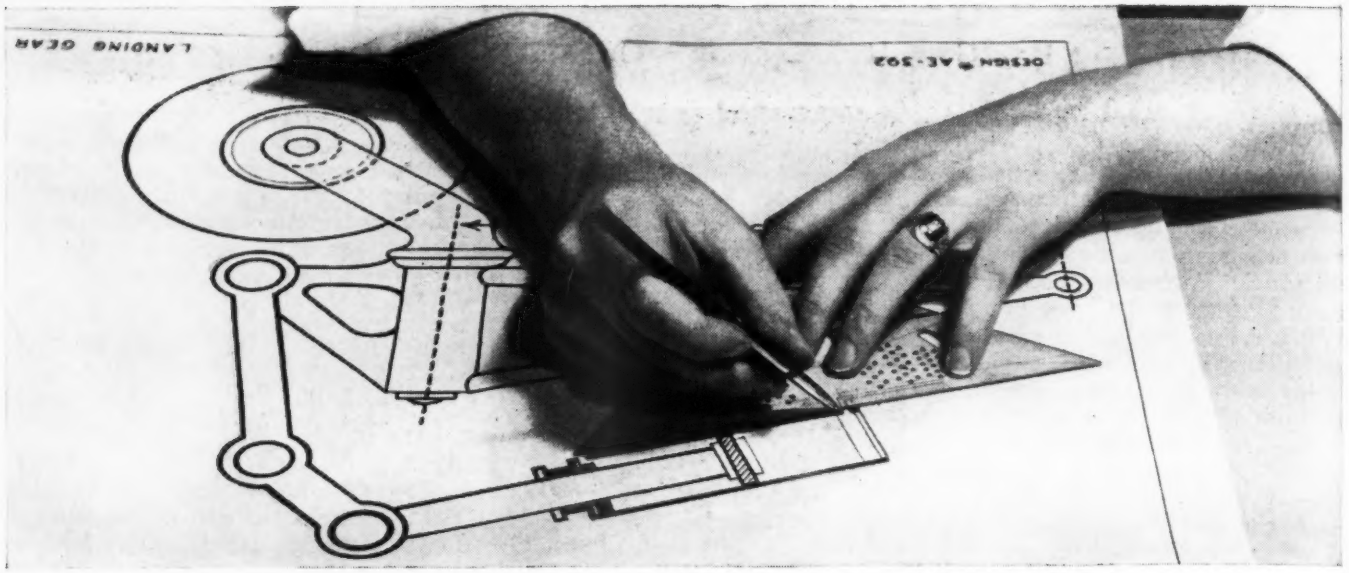
BRITISH INDUSTRIES FAIR—Sponsored by Export Promotion Dept., held in London and Birmingham.

May 6-7

ANTHRACITE CONFERENCE — Annual Conference at Lehigh University, sponsored by Anthracite Institute and Lehigh University.

May 7

AMERICAN INSTITUTE OF CHEMISTS—Annual Meeting, Waldorf-Astoria Hotel, New York, N. Y.



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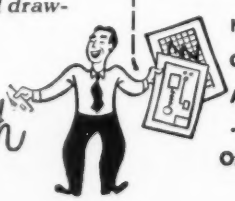


Contact Ratio Charts for Designing Spur Gears

WAYNE H. BOOKMILLER
Gear Engineering Division, General Electric Company

CONTACT RATIOS of various sets of gears are frequently calculated to help determine which set will give best service in a particular installation. Usually each gear set is considered as an individual case and a special calculation or layout made. These charts have been prepared to minimize calculation and avoid repetition.

A series of tooth form layouts were made to cover a wide range of tooth numbers for 20 deg pressure angle gears. Layouts were made for standard and long-short addenda gears. The data compiled from these layouts are presented in chart form.

As an example of the use of the charts, consider this pinion and gear that have standard addenda:

	Pinion	Gear
Number of teeth	28	85
Diametral pitch	20	20
Pressure angle, deg	20	20
Pitch diameter, in.	1.400	4.250
Addendum, in.	0.050	0.050
Tooth thickness, in.	0.077	0.077

The contact ratio, M_P, for this gear set is 1.735, as read on the graph of Fig. 1.

The graph of Fig. 2 gives the addenda for equal Y

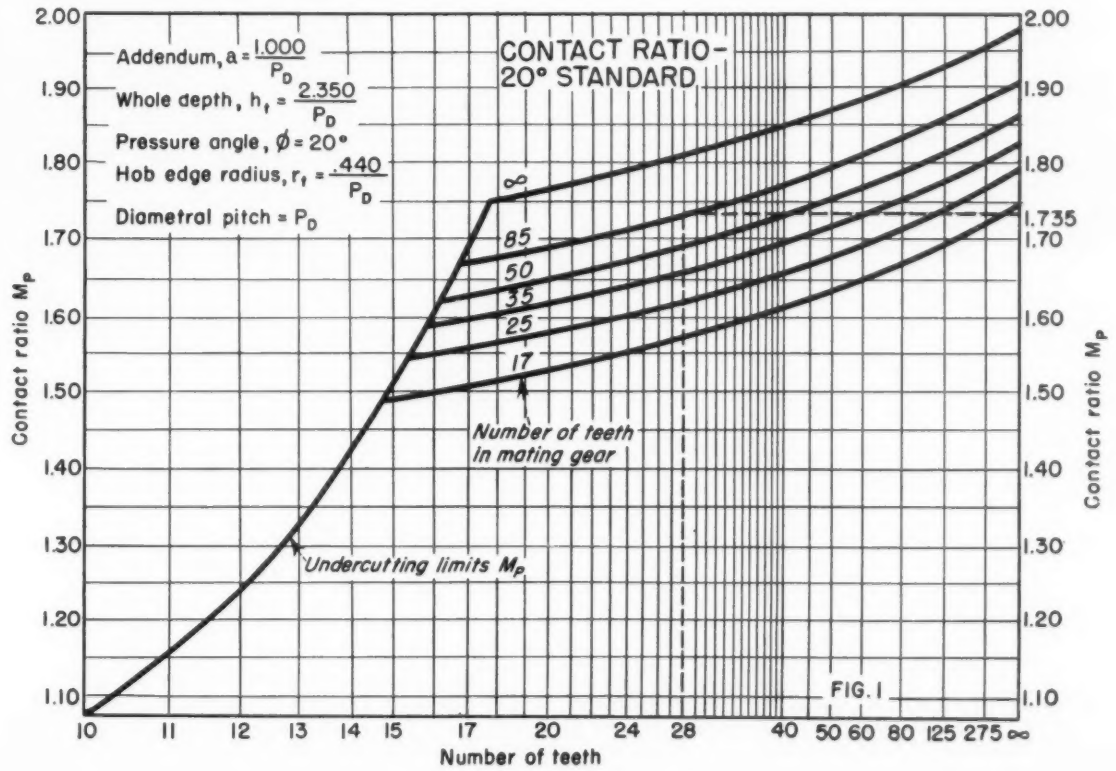
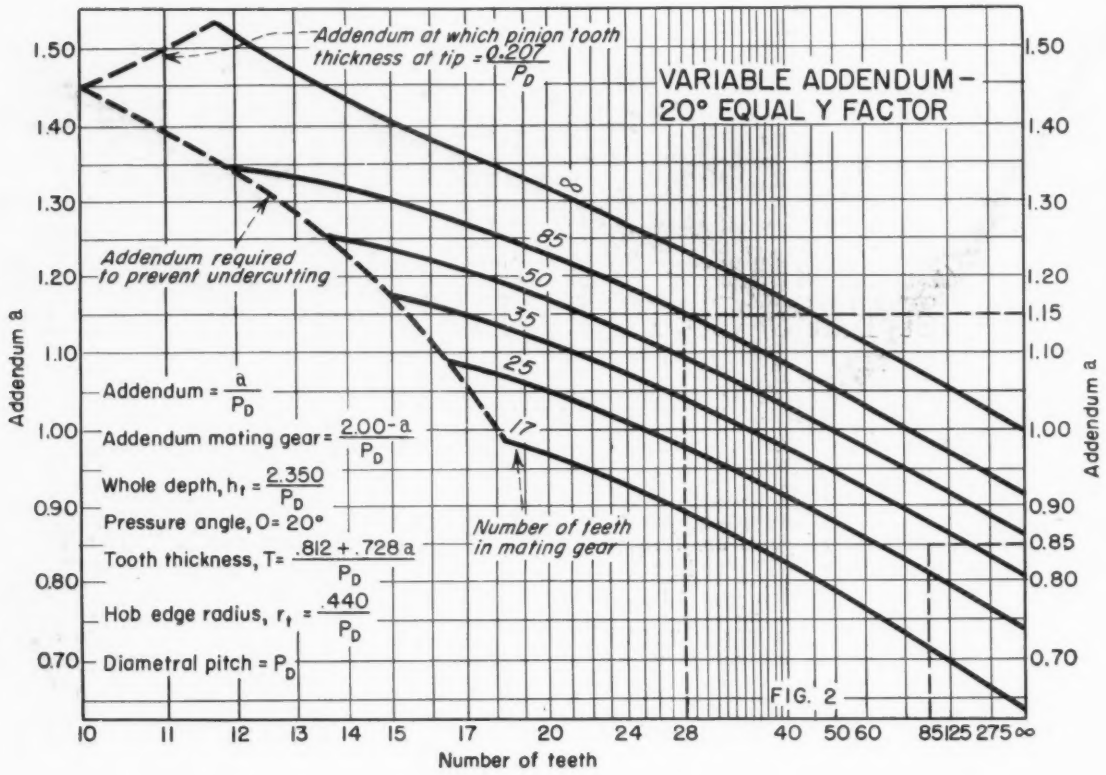
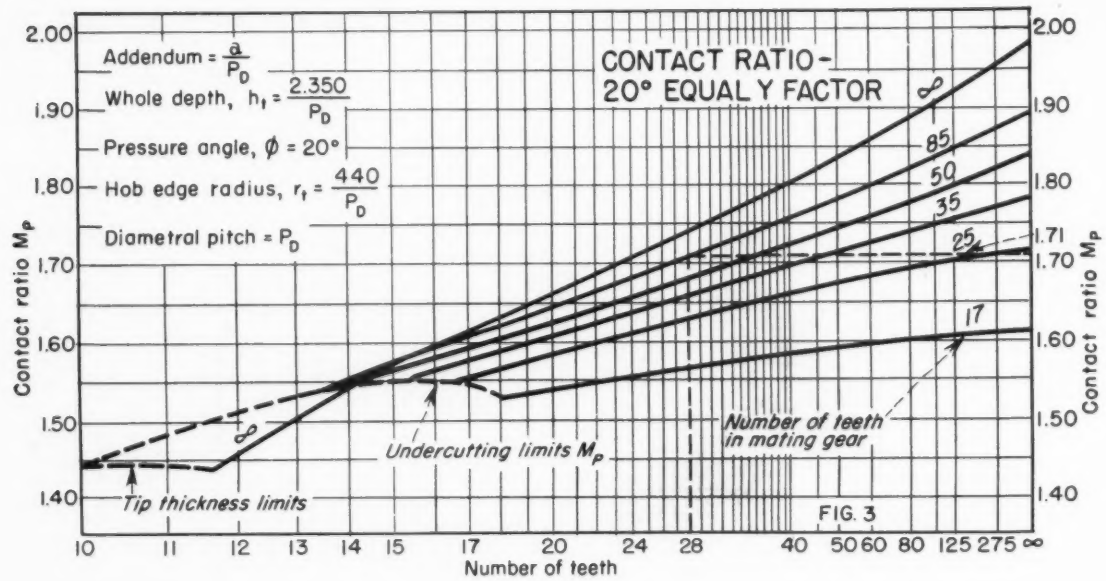


FIG. 1


VARIABLE ADDENDUM – 20° EQUAL Y FACTOR
Addendum at which pinion tooth thickness at tip = 0.207 / P_D
Addendum required to prevent undercutting
Addendum = a / P_D
Addendum mating gear = 2.00 - a / P_D
Whole depth, h_t = 2.350 / P_D
Pressure angle, O = 20°
Tooth thickness, T = .812 + .728 a / P_D
Hob edge radius, r_t = .440 / P_D
Diametral pitch = P_D
Number of teeth in mating gear
∞ 85 50 35 25 17
Addendum a
Number of teeth
FIG. 2


CONTACT RATIO – 20° EQUAL Y FACTOR
Addendum = a / P_D
Whole depth, h_t = 2.350 / P_D
Pressure angle, ϕ = 20°
Hob edge radius, r_t = 440 / P_D
Diametral pitch = P_D
Undercutting limits M_p
Tip thickness limits
Number of teeth in mating gear
∞ 85 50 35 25 17
1.71
Contact ratio M_p
Number of teeth
FIG. 3

factor gears and indicates the formula for calculating tooth thickness.

As an example: Design a long-short addenda gear set using the initial data of the previous problem. On Fig. 2, read the indicated addenda: 0.85, gear; 1.15, pinion. By dividing the diametral pitch into these values, the actual addenda are found: 0.0425, gear; 0.0575, pinion. The tooth thicknesses are then calculated to be: 0.0715, gear; 0.0825, pinion. The contact ratio for this gear set is read on Fig. 3 as 1.710.

It should be noted that strengthening the pinion, by using a long addendum pinion and a short addendum gear, reduces the number of teeth in the arc of action.

When it was found, Fig. 3, that the line for a rack as a mating gear crossed over other mating gear lines, additional layouts were made and carefully checked. The fact that the lines did cross was confirmed, and the crossover point was accurately located.

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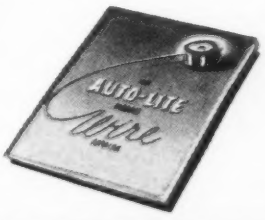

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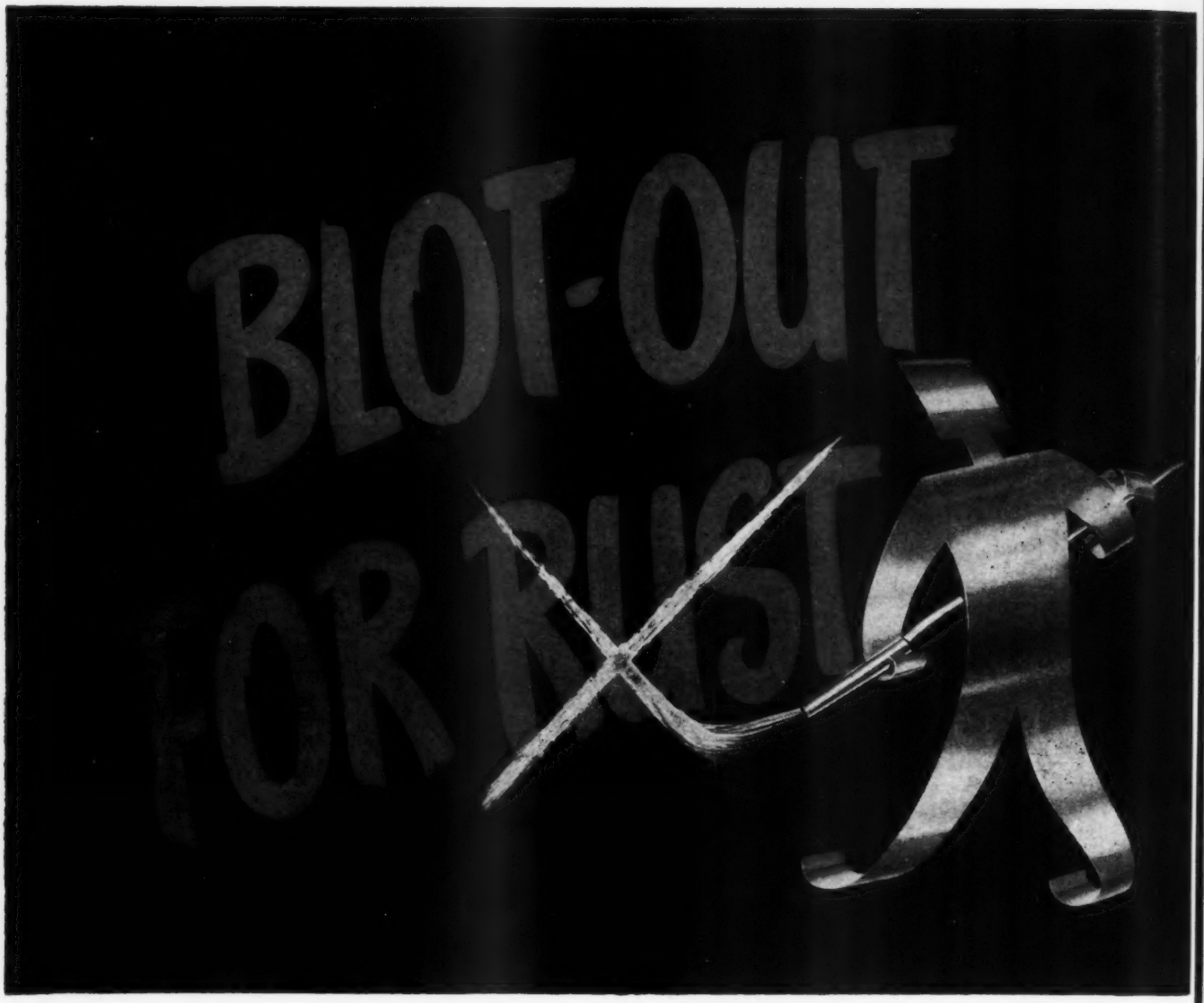

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NEW MATERIALS AND PARTS

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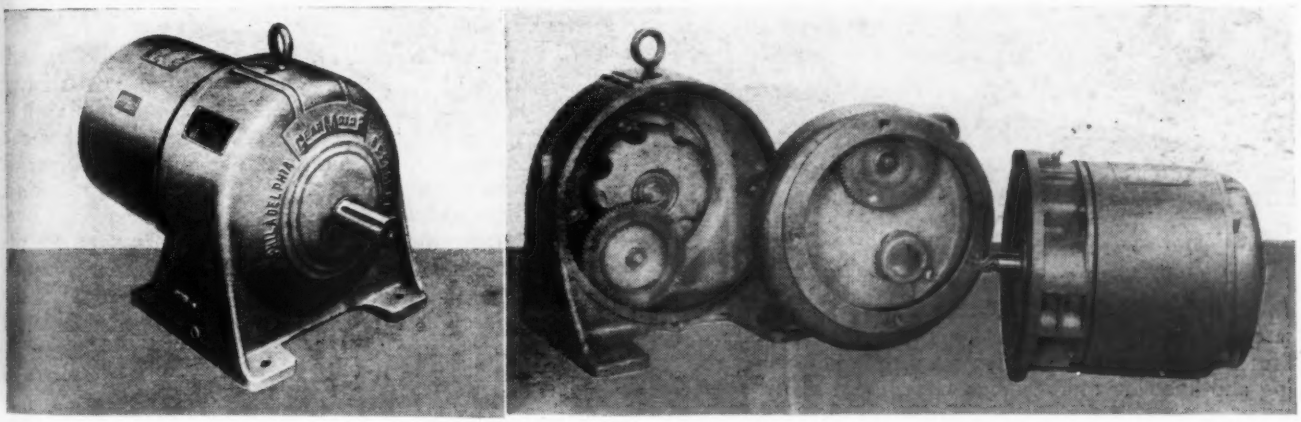


Compact Gearmotors for Industrial Applications

Reliance Electric & Engineering Co., Cleveland 10, Ohio and Philadelphia Gear Works, Inc., Philadelphia 34, Pa.

Built in six basic sizes capable of delivering from 1 to 60 hp, compact, packaged gearmotors operate in a speed range from 7½ to 780 rpm. Single-, double-, or triple-reduction units are available in each size. Use of a flange-mounted motor, complete with bearings and bracket, permits the adaptation of many standard or special motor enclosures. These include open, splash-proof, protected, fan-cooled, enclosed, Underwriters' Class I Group D, Class II Group F and G, and Bureau of Mines' types that can be bolted to any of the gear elements without alteration.

The single reduction unit comprises a cast iron housing. Output shaft is located centrally, above the feet of the motor and splash oil lubrication is provided for the helical pinion and gear. In the double reduction unit, the feet are cast integral with the housing. Output shaft is mounted in anti-friction bearings, one mounted in the housing, the other in a centerplate. The plate also serves as a support for the pinion of the final reduction in the two-stage reducer. A footless motor is bolted directly to the reducer. The pinion, assembled to the motor shaft, engages with the gear driving the second reduction pinion. The same high speed gears are used in both the two-stage and single-stage assemblies. The three-stage gearmotor is made by adding a one-stage assembly bracket to the two-stage gearmotor.

On the multi-stage units, only a bearing separates the output shaft and the feet of the gearmotor. This mechanical feature provides sturdiness, particularly important with high torque loads, especially at low speeds and also minimizes the possibility of oil leakage.

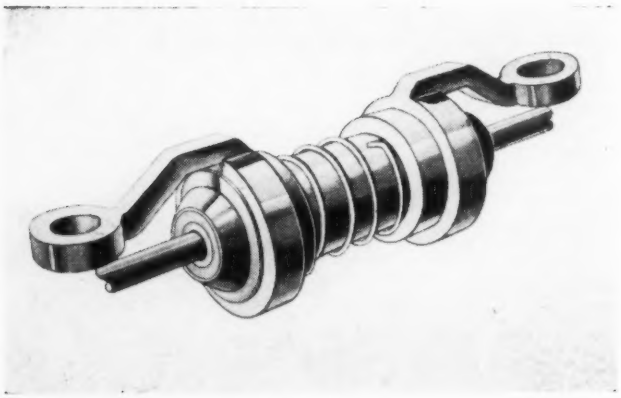
A high degree of standardization has been attained in the induction-hardened high speed gears. Since output speeds are based on a geometric progression, the gear ratios fall in the same pattern. In the single-stage assemblies, only five gear ratios are used; in the multi-stage types, two ratios are used in the final-stage reduction. This simplification has reduced the number of gears in a set from 324, for a previous design, to 42. Standardization also means that one set of gears will serve a number of gearmotors. All assemblies have each pinion and gear well supported and spaced to reduce deflection and to permit high load carrying capacity. Anti-friction bearings are used throughout.

For long-service life, tolerances are closely held by machining the multi-stage housings from one end. This permits machining of the adapter fit, center plate fit and the bearing bore from a common center.

The design of the housing, with centerplate nested into it, allows a grouping of gear loads that results in the

cancellation of loads and reduces the resultant strains. This "balanced integrated dynamics" condition produces a design that is sturdy and free from vibration, yet capable of carrying high loads.

Units have been built for hard-pulling jobs. The short, low-slung design produces maximum horsepower for a given frame size. With the output shaft centrally located between the feet units can be located in spots that are hard to get at or into. They can be assembled and maintained in very tight corners, such as in mining machinery. Because the entire assembly of the gearmotor is accomplished from one end, it can be spotted into the cavity of a machine tool, making it an integral part of the machine.



Safety Cord Swivel

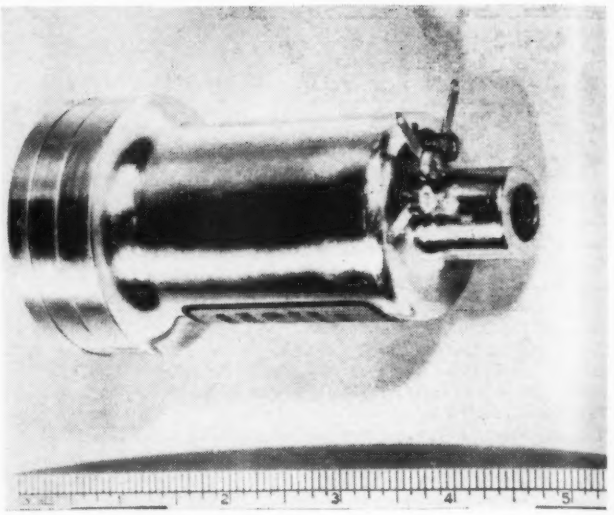
Burlington Instrument Co., Burlington, Iowa

Applied to wall plug, appliance plug or cord contact, the safety swivel minimizes the dangers of short circuits and fires resulting from insulation breakage. Twisting, curling and knotting cannot occur as each end of the unit is free to rotate. The device consists of two sleeve-type sections precision fitted inside each other and assembled with insulation between. End swivels are held in position by music wire springs and lead pins extend from internal contact swivels through guides at each end. Wire connections can be made at the pins or internally with the pins removed. All swivels have three points of contact assuring constant flow of current and minimum static. When applied in a cord. a special bakelite case with insulating bushings is supplied. Standard units are made for 125 v, 10 amp capacities.

Insulating Tubing

The National Varnished Products Corp., Woodridge, N. J.

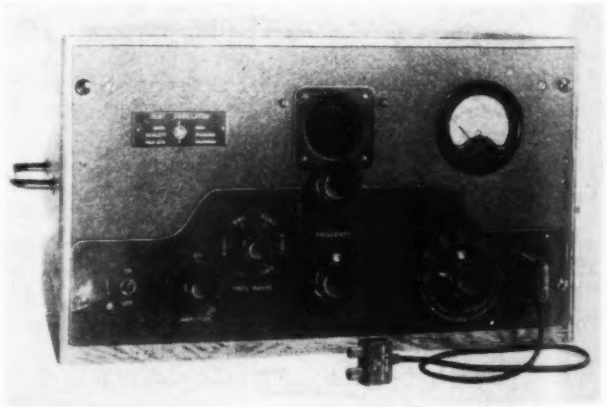
Natvar 400 extruded vinyl insulating tubing is noninflammable, has high resistance to oil and withstands continuous operating temperatures up to 105 Centigrade. It does not crack with age and can be made clear or in a variety of colors. Applications include all types of internal wiring for electrical equipment where coated fabric sleeving and tubing have been specified. Recent approval tests conducted by Underwriters' Laboratories, Inc. on samples ranging in size from No. 24 to $1\frac{1}{2}$ in. show the following electrical characteristics: maximum voltage rating, sizes No. 18 and smaller—300 volts; sizes $\frac{3}{8}$ in. and larger—600 volts; dielectric strength—2,500 v a-c; insulation resistance—3,060 to 3,820 megohms per 1,000 feet.



Pressure Transducer

G. M. Giannini & Co., Inc., 285 W. Colorado St., Pasadena 1, Calif.

Type 4713 transducer is sensitive to pressure differentials in the range of $\pm$ 20 in. water. Measurement is based on the slack-diaphragm principle. One end of a spring-linkage movement is attached to the dome, the other end to a bellows. A microtorque potentiometer wiper is fastened between counter-wound halves of the spring. As the bellows responds to changes in pressure, movement is transmitted through the spring linkage to the wiper, causing it to move in a wide arc on the potentiometer coil. Large voltage outputs, dependent on the coil resistance, are therefore the result of extremely small changes in pressure. Weighing 6 oz and measuring $3\frac{7}{8}$ in. long and $1\frac{7}{8}$ in. in dia, this device is suited for use with galvanometer-recorders, strain gages, and telemetering links.



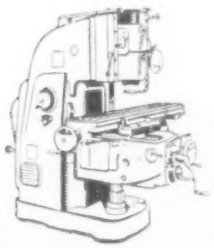
Resistance Tuned Oscillator

Hewlett-Packard Co., 395 Page Mill Rd., Palo Alto, Calif.

The hp Model 650A Resistance Tuned Oscillator provides audio measurement speed, ease and accuracy for readings at r-f, video and audio frequencies. Instrument covers a frequency range of 10 cycles to 10 megacycles, in decade ranges. No zero setting is required and minimum adjustments are necessary during operation. Operation is virtually independent of line voltage and tube

Extra S.A.*

without extra cost



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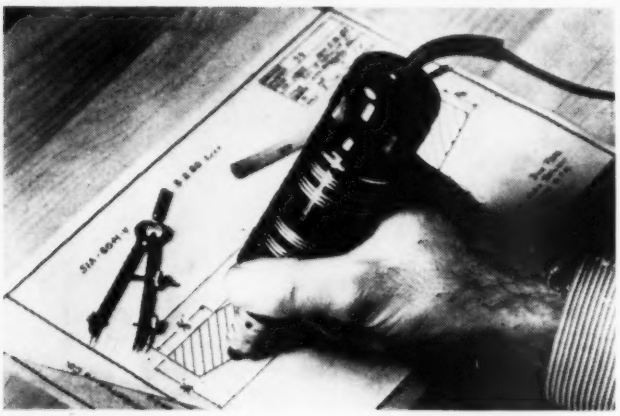
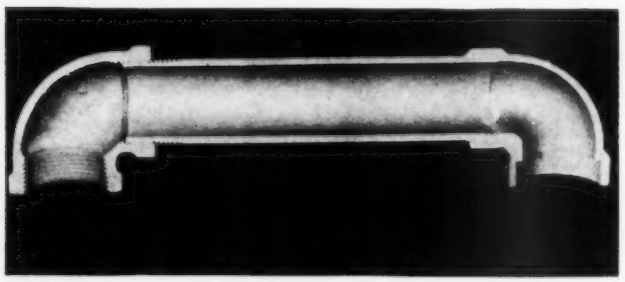
characteristics changes. Output is flat within 1 decibel at all frequencies and voltage range is 0.00003 to 3 volts. Output impedance is 600 ohms, but a 6 ohm impedance is available through an output voltage divider supplied with the instrument. Other features include a 94 in. scale length, a 6 to 1 micro-controlled vernier tuning drive and a complete vacuum tube voltmeter to monitor output in volts or decibels at the 600 ohm level. Continuously variable output voltage is obtained by means of an output attenuator of 50 decibels, variable in 10 decibel steps, and an amplitude control which adjusts the level to the monitoring vacuum tube voltmeter. Operating entirely from a 115 v a-c power supply, the equipment is provided either in relay rack or cabinet mounting. Panel size is 19 x 10½ inches.



Electric Drawing Eraser

Chicago Wheel & Mfg. Co., 1101 W. Monroe St., Chicago 7, Ill.

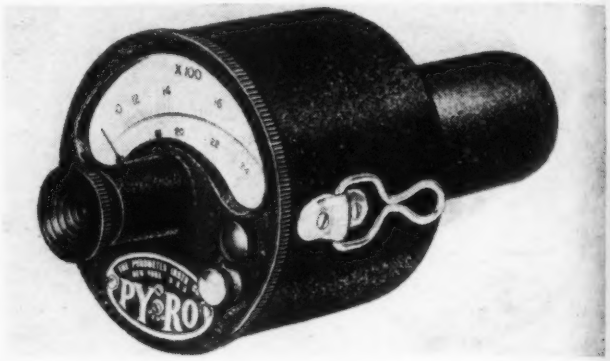
Smooth, clean erasures without smudge on tracings and drafting room copies can be effected in a few seconds with this electrically driven eraser. Balanced and shaped to fit the hand, all moving parts except the rubber eraser are completely covered by a protective sleeve. The quick-change chuck accepts any of the standard erasers. Optional equipment includes a foot operated "on" and "off" speed control that provides freedom of both hands at all times.



Threadless Pipe Fittings

G. M. Basford Co., 2020 Lincoln Bldg., 60 E. 42nd St., New York 17, N. Y.

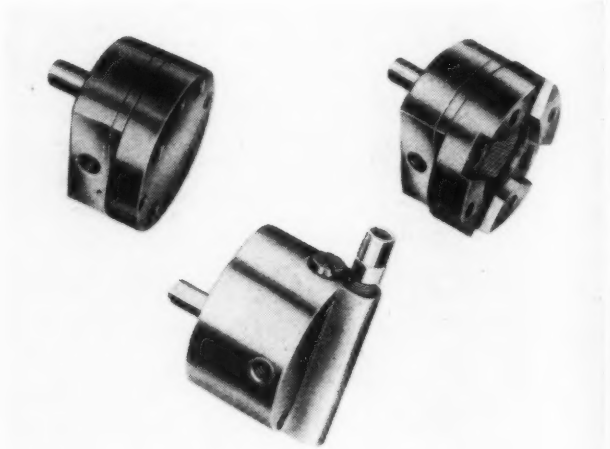
Minimum pressure loss due to friction and turbulence in piping systems is achieved through the use of Flagg-Flow threadless fittings. (See right end of cut.) Made of black, malleable iron, the fittings are the socket type suitable for brazing to steel or wrought iron. The cup is reamed to the OD of standard pipe, providing a shoulder and rigid support for the pipe. The design permits full wall thickness and maximum pipe strength since no metal is removed by threading. Silver brazing alloys with melting points of 1170 F and higher and an oxyacetylene torch are used for making the connections on the job. A typical industrial installation using these fittings is one involving temperatures up to 450 F and pressures up to 300 pounds per square inch.



Spot-Temperature Pyrometer

The Pyrometer Instrument Co., 103 Lafayette St., New York, N. Y.

The Pyro Radiation Pyrometer is designed for rapid, accurate measurement of temperatures above 1,000 F. Weighing two pounds, the instrument is direct reading and requires no outside connection to batteries or other accessories. Simple operation consists of sighting the vacuum thermocouple on the front at the object being measured and reading the temperature on the scale. The meter needle is locked at the reading obtained and can be released by pushing the button. The steel housing provides durability and acts as a shield against external magnetic and electrical influences.



Small Capacity Gear Pump

Bijur Lubricating Corp., Long Island City 1, N. Y.

All three models of this constant feed gear pump are designed to provide 50 cc per min at 100 rpm for lubricating systems in all types of machines. Because of the small capacity, the correct amount of lubricant can be

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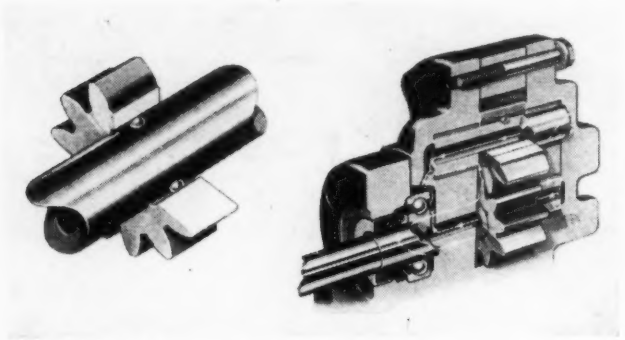
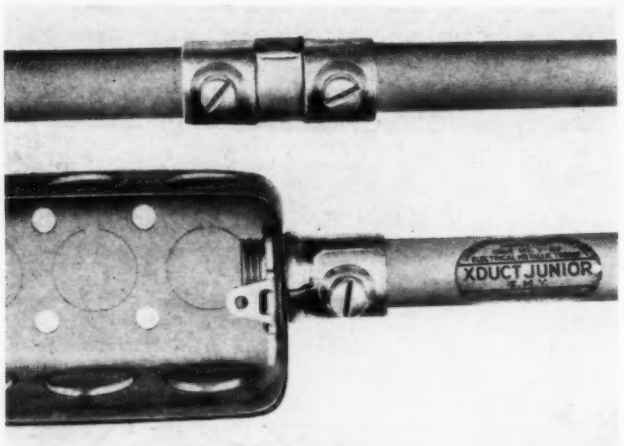
delivered without by-passing a high percentage of the output. The universal model (upper left) can be mounted in any position, the direction of rotation determining the direction of flow. The reversible unit (center) maintains flow in one direction only, regardless of shaft rotation. The third pump (upper right) is equipped with a fine mesh screen and can be mounted in the oil sump. Base diameters measure 2½ in., making all models readily adaptable to machines where space is limited.



Hydraulic Gear Pump

Adel Precision Products Corp., Burbank, Calif.

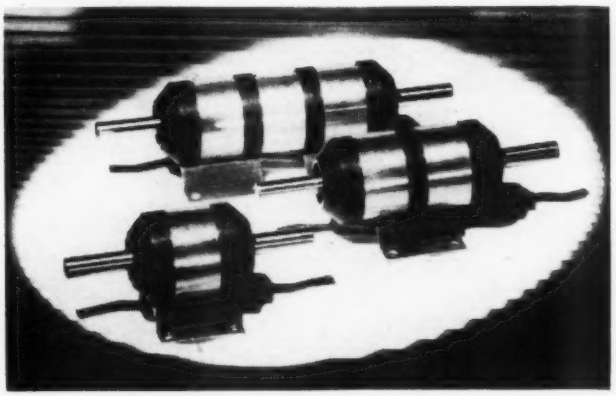
Special gear mountings and pressure lubrication characterize this gear-type hydraulic oil pump. A ball drive permits the gears to float endwise on the shafts thus preventing thrust loads from being transmitted from the shaft to the gears. Working parts are pressure lubricated as indicated by oil trapped in the gear compartment. Precision-machined hardened steel gears and shafts and a special oil seal and ball bearing in the drive shaft contribute to the durability and dependability of the pump. Adaptable to industrial and farm machinery applications, the unit is designed to produce 1,000 psi pressure at 1,800 rpm in various models having rated capacities from 1.5 to 60 gallons per minute.



Electrical Conduct Connectors

National Electric Products Corp., Chamber of Commerce Bldg., Pittsburgh 19, Pa.

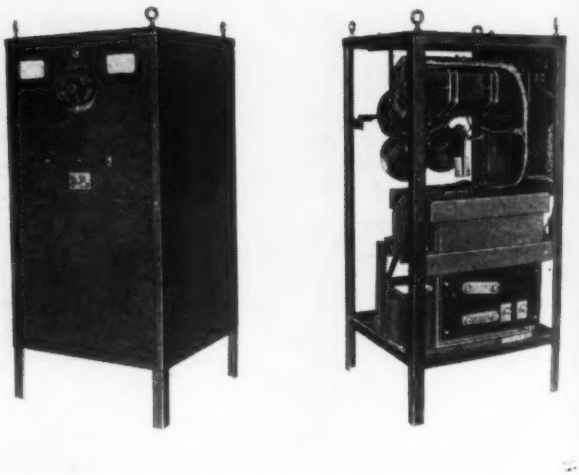
Electro-galvanized E. M. T. pressed steel couplings and connectors are well adapted for installations where space is limited. The fittings slip over thin-wall tubing ends with a close, accurate fit. Positioning is controlled by a small integral step. When the screw head is driven down against the boss, the screw tip embeds in the tube wall just enough to give a vibration-proof, permanently grounded connection. Easy to install and inspect, these fittings are approved by Underwriters' Laboratories.



High-Ratio Speed Changers

Metron Instrument Co., 432 Lincoln St., Denver 9, Colo.

Standard 1-, 2- or 3-section miniature speed changers provide ratios as high as 3,375 to 1 for low power applications. Diameter of the units is 1.05 in. and overall lengths are 3, 3⅞ and 4⅝ in., respectively. Applicable to developmental work and as component parts in finished parts, over 500 different speed ratios can be supplied. Speeds as high as 20,000 rpm and torques of 2 lb-in. are practical. Hardened steel gears are used throughout and, for most applications, lubrication is permanent. Input and output shafts are concentric and supported on ball bearings.



High-Current Rectifier

Mellophone Electronic Rectifier Co., Inc., Rochester 2, N. Y.

A line of low-voltage high-current rectifiers is available for operation from 220 or 440 v three phase a-c power lines. Output voltage can be varied from 0 to 6 v d-c with a capacity of 600 amp or from 0 to 12 v with 300 amp capacity. Although intended for use in electroplating and electrolytic cleaning systems, the units provide

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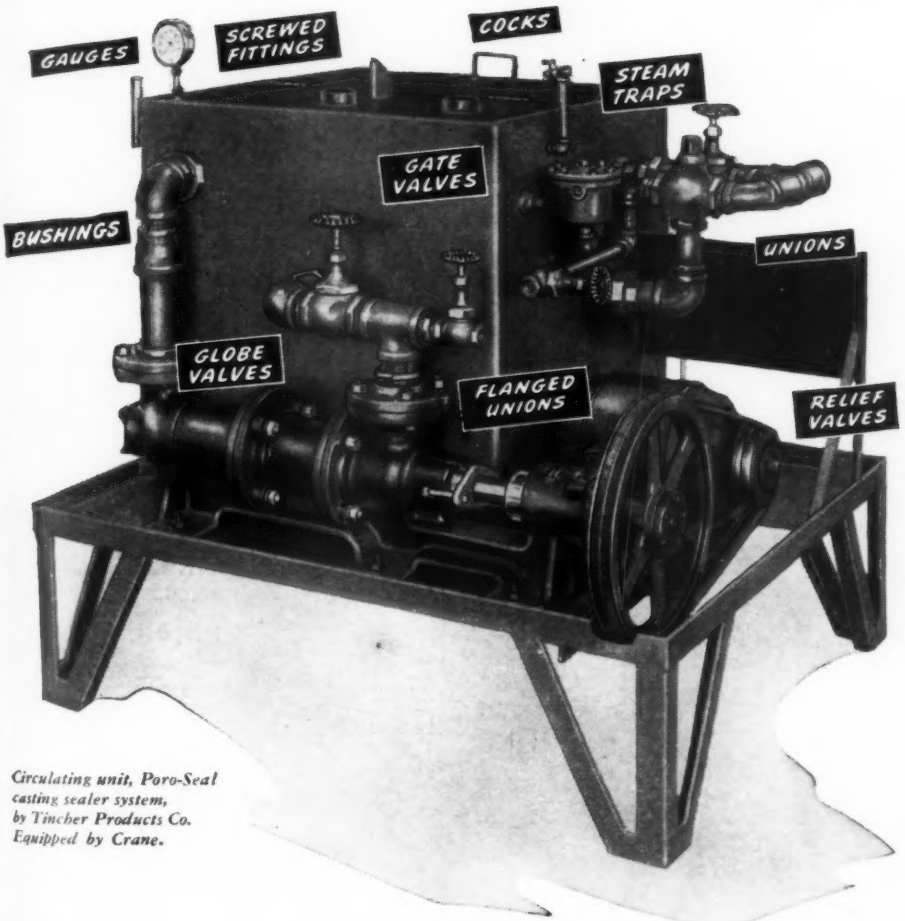
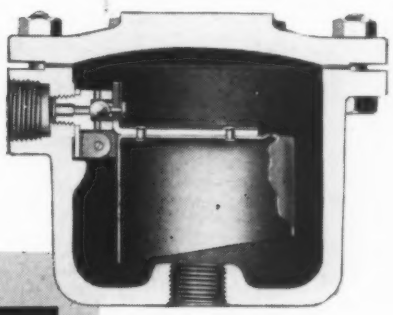


Circulating unit, Poro-Seal casting sealer system, by Tincher Products Co. Equipped by Crane.

SIMPLIFIED STEAM TRAP, CRANE No. 981 *has only one moving part. Keeps steam lines hot and dry; saves fuel. Works automatically; requires virtually no maintenance. Compact design; ideal for steam-heated or steam-operated machinery. Easy to install and service. Made in 150, 200 or 300-pound steam pressure classes. See your Crane catalog or write for literature.*



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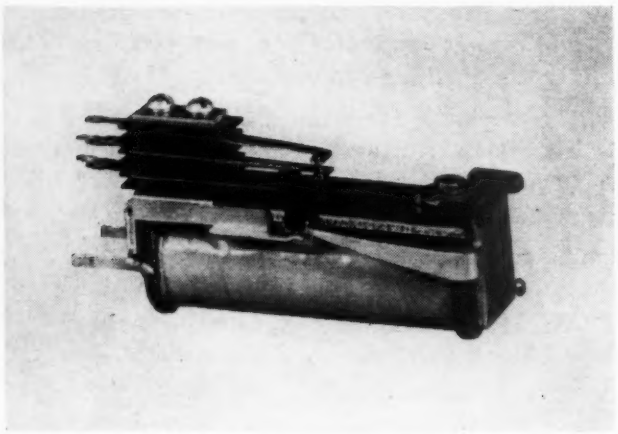
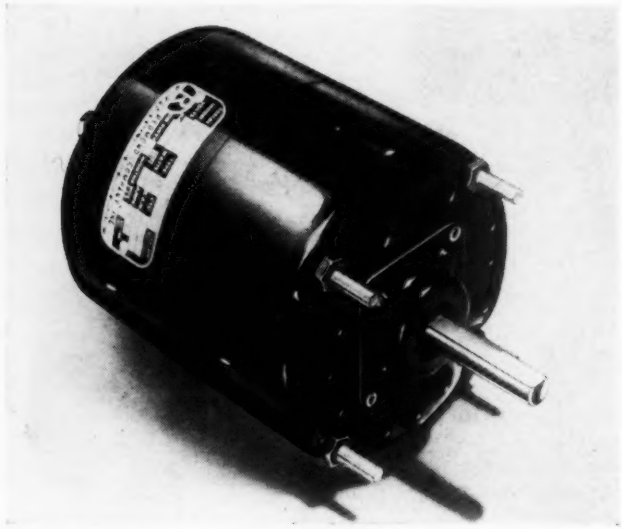
an ideal power source for testing and running-in 6 v and 12 v d-c motors. Rectifying elements are sealed selenium type and heavy duty transformers give stepless control over output voltages from zero to maximum setting. Protection against overloads and ventilation system failure is provided.



Multi-Contact Relays

General Electric Co., Schenectady 5, N. Y.

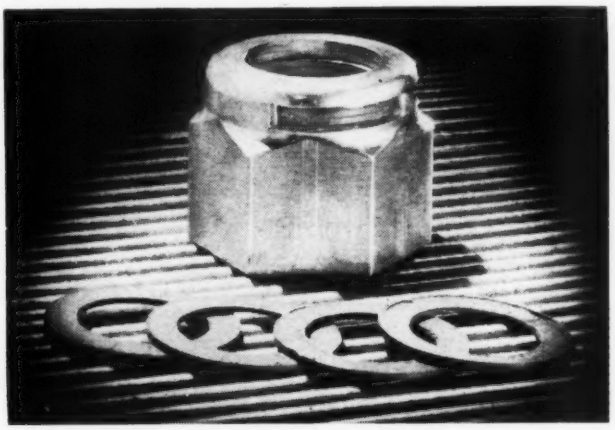
A new multi-contact d-c relay capable of handling as many as 12 circuits in a wide variety of contact combinations has been designed for use in industrial electronic apparatus, communications, and signaling equipment. Working from five basic contact arrangements, combinations can be stacked to satisfy intricate circuit switching requirements. Silver, palladium, or tungsten contacts can be supplied, the choice depending upon rating and life specifications. More than 500 different coils are available for use in the relay with ratings ranging from 1 to 250 v and from 0.1 to 26,000 ohms. Coil voltage and resistance can thus be closely matched with the rating of the energizing circuits. Two-section or concentric two-winding coils are also available.



Fractional Horsepower Motor

Redmond Co. Inc., Owosso, Mich.

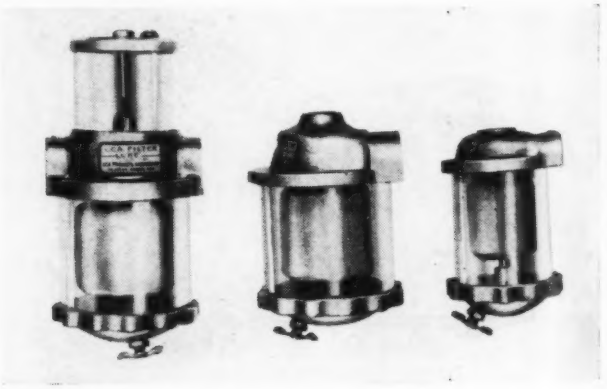
Type "W" 1/15th hp shaded-pole motor incorporates design improvements that make it ideal for use in air circulators, window type ventilators, unit coolers, evaporative coolers, exhaust and pedestal fans. Long life is assured by a large capacity lubricating system that circulates oil through porous bronze bearings. This type bearing is said to retard gumming, filter the lubricant and provide a steady flow of oil directly to the 2 sq in. of bearing surface. Bearings are spring-tension centered and broadly spaced to provide smooth operation. The precision skewed flush-weld rotor is micro-balanced and has a machined surface, rust inhibited. There are no open inductor slots to collect dirt and dust. Operation of the Type "W" is at 1,500 rpm on 115 v, 60 cycles. Housing length is $5\frac{1}{8}$ in., diameter is 3 15/16 inches.



Nut with Replaceable Lock Ring

Swallow Airplane Co., Wichita, Kans.

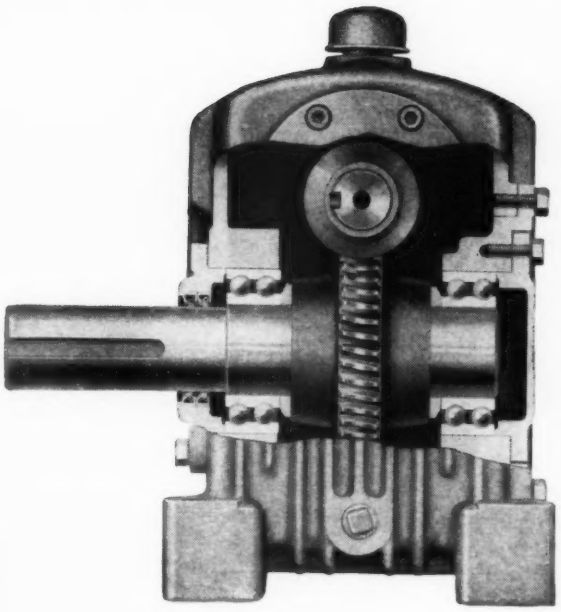
A lock nut with replaceable locking ring that can be used with either fiber or metal washers permits usage where resistance to heat is essential. Full holding strength in excess of AN specifications is restored by replacing only the locking unit retained in the crown of the nut. This low cost replacement feature effects appreciable savings in many instances such as on nut plates that are either riveted or spot welded to assemblies. Aside from the saving on the nut plate, the time factor of replacement and danger of damage to the entire assembly is reduced. The lock nut lends itself to greater use in the larger sizes.

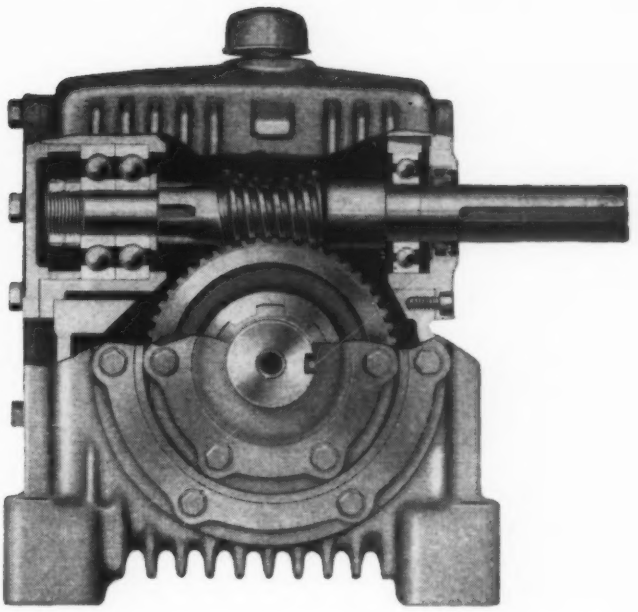


Air Filter-Lubricators

CCA Products, Inc., Box 671, Glendale 5, Calif.

Transparent, plastic bowl filter lubricators and single air line filters have large area bowls and elements that per-





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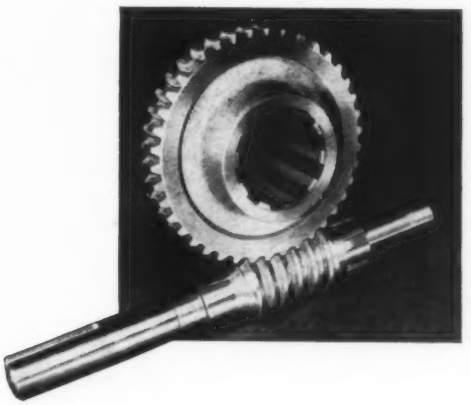
632 HP with an 18" GEAR*SET?

*CENTER DISTANCES

Impossible? These are the actual ratings of some Cone-Drive gear sets at 1750 rpm. The larger gear set can actually handle 600,000 INCH POUNDS of torque at 100 rpm.

These *standard* Cone-Drive gear sets and speed reducers—with their greater contact per tooth and MORE TEETH IN CONTACT—are available in ratios of 5:1 to 70:1 and from fractional hp to hundreds of hp.

Write for complete information today, giving your approximate hp or torque and speed requirements.



CONE-DRIVE

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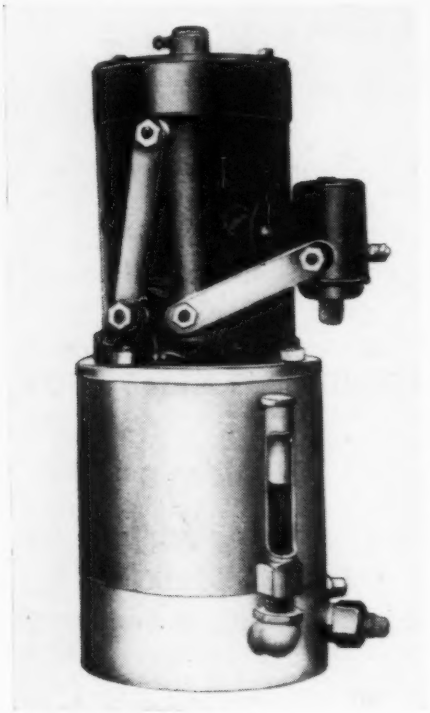
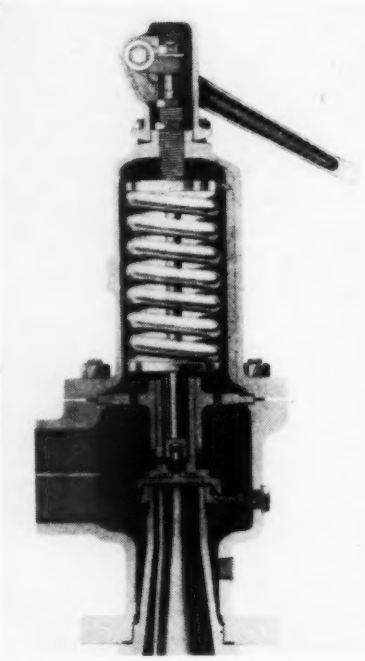
mit maximum capacity and reduce maintenance. All-wool felt filter elements, easily replaceable, provide protection against sludge, dust, sand, oil, scale and free moisture for all types of air-operated equipment. O-ring packings seal the units and a single hold-down screw permits rapid disassembly. The Filter-Lube unit on the left is an air line filter and automatic lubricating injector combination, completely air actuated. A precision metering device provides the correct amount of oil to mix with clean, dry operating air.



Fluid Power Unit

Jerome Hydraulics Co., 60 Ocean Ave., Lynbrook, N. Y.

Model 1100 Pack O'Power is adaptable to single cylinder, gravity or spring return applications requiring up to 1½ hp intermittent duty rating. Except for the ram itself, unit is a complete hydraulic system including 6 or 12 v motor, pump, reservoir, circulating oil filter, relief valve, check valve, electrically operated by-pass valve and return flow regulator for constant rate of ram descent. Interchangeable pumps are available for pressures up to 2,000 psi or flow rates up to 4 gpm. Assembly is 5¾ in. OD by 14 in. high and can be mounted vertically or horizontally. Reservoir holds 85 cu in. and connections are available for an auxiliary tank. All valves are externally assembled for ease of service. Other models include 110 v, belt driven and double acting cylinder actuation.



Safety-Relief Valve

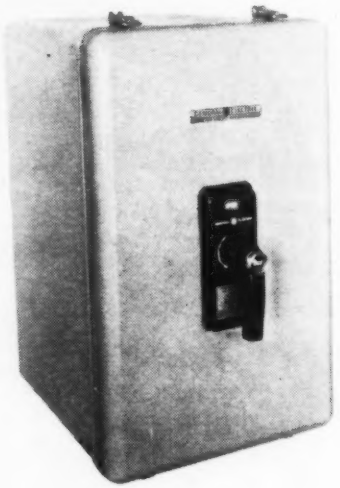
Farris Engineering Corp., 527 Commercial Ave., Palisades Park, N. J.

Type 2680 safety-relief valve is designed for handling corrosive liquids, vapors or gases at 2,000 psi pressure and temperatures up to 900 F. Valve lift ratio is 2½ to 1 and disk guide assures positive reseating. The long, low-stressed protected loading spring maintains accuracy of any set pressure. A modification of the valve has all working parts isolated behind a "Farriseal" of rubber, neoprene or any flexible metal, designed to withstand the action of specific acids and caustics. Steam coils can also be mounted internally to maintain fluid temperature for very viscous materials. Valve sizes range from 1½ x 2 in. to 6 x 8 inches.

Electric Air Control Valve

Hannifin Corp., 1101 S. Kilbourn Ave., Chicago 24, Ill.

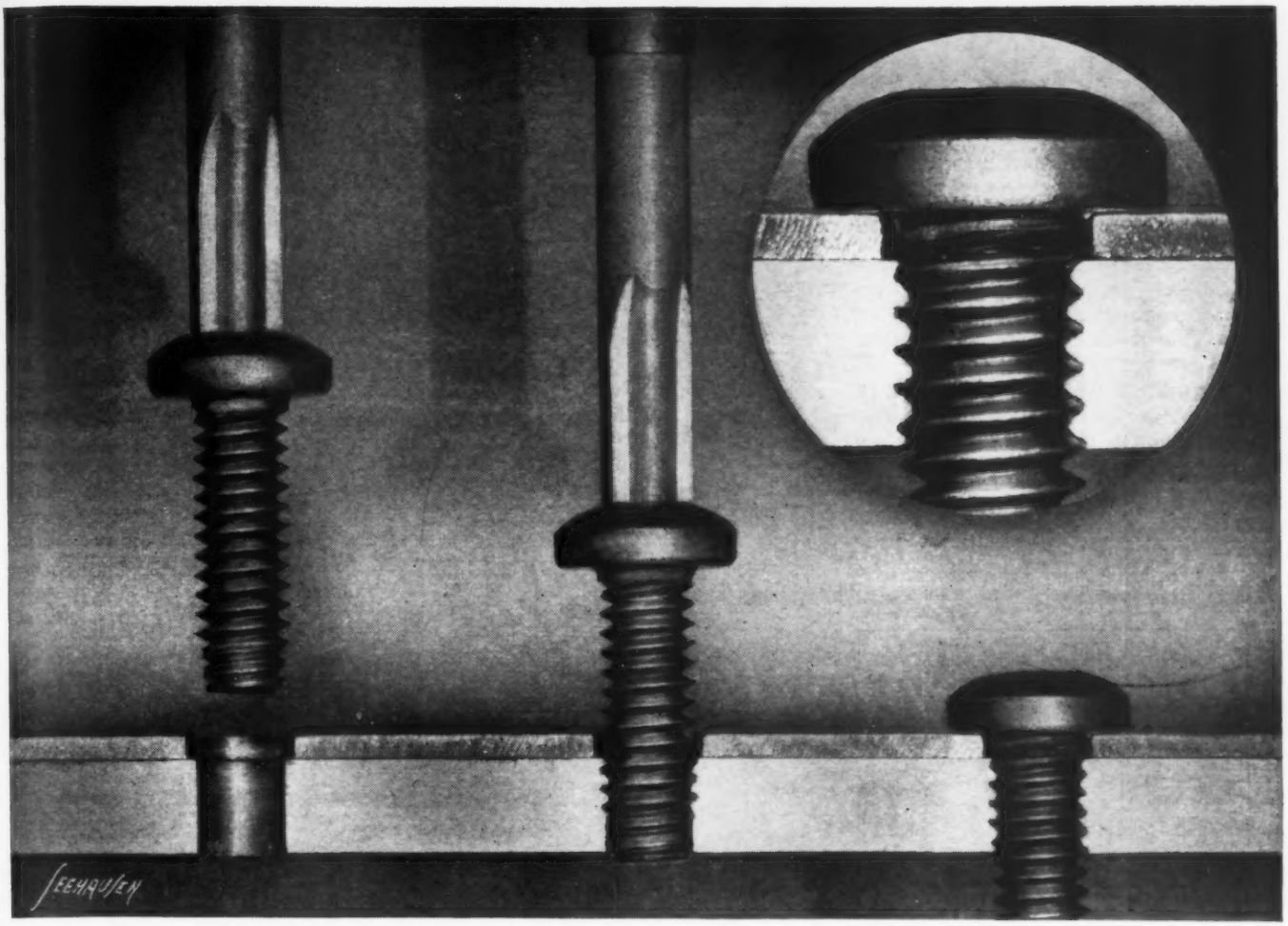
Designed primarily to provide a fast-acting push button control for small, air operated presses and similar units, electrically operated 4-way valve also has application as an automatic control for any air operated unit through the use of limit switches or mechanical stops. The valve itself is the packless reciprocating disk type, pilot operated and solenoid controlled. It is built in two types: Type I is arranged for double solenoid operation using two push buttons or limit switches. Valve position is determined by energizing the proper solenoid. Type II is arranged for power offset operation using a single push button or limit switch. The valve returns to its initial position when the solenoid is de-energized. Either type is capable of as many as 180, or more, operating cycles per minute in handling any air pressure from a minimum of 25 psi to a maximum of 150 psi. Type I units are rated at 10 watts, Type II at 20 watts. Standard models are built for 115 v, 50-60 cycle circuits, but they can also be supplied for 230 v, 50-60 cycle power, or for d-c, low voltage a-c, and other frequencies.



Air Circuit Breaker

General Electric Co., Switchgear Div., Schenectady, N. Y.

Two models of Type AK-1 air circuit breaker are available for low voltage circuits—600 v and below. The AK-1-15 is rated 15 to 225 amp with a 15,000 amp interrupting rating; AK-1-25 is rated 35 to 600 amp with a 25,000 amp interrupting rating. Characteristics of the breaker include improved arc interruption, compact sealed-in overload trips, short-time rating equal to the interrupting rating, complete shielding of live parts, and an all-metal mounting base. Arcing



Here's How CLUTCH HEAD SCREWS *Solve All Thread-forming Problems*

No Washer, Nut, or Other Auxiliary Fastener Required

1 ***Clutch Head Thread-forming Screws*** are single-unit fasteners because they form mating threads which are tailor-made to merge snugly with the threads of each individual screw.

2 ***The Result*** is a vibration-proof one-unit fastening . . . actually integrated in a solid wall of metal.

3 ***Thus a 3-Way Saving***—elimination of separate tapping operation; cost of multiple fastenings; and cost of slow-down in two-handed assembly.

4 ***The Design of the Clutch Recess*** is "a natural" to meet the rigor of the toughest thread-forming job.

5 ***Note the Husky Teeth*** of the straight-walled recess . . . to stand up under the highest torque required.

6 ***Also Consider*** the rugged structure of the straight-sided Type "A" Bit for longer uninterrupted service.

7 ***It Is Important*** to the safety and speed of assembly operation that the CLUTCH HEAD engagement is *definitely non-tapered.*

8 ***Hence, There Is No "Ride-out"*** to combat . . . eliminating both the skid hazard and need for fatiguing end pressure.

9 ***Freedom*** from burred or chewed-up heads also speeds assembly. The Center Pivot column guides driver into dead-center entry for automatic straight driving.

10 ***Note How the Lock-On,*** exclusively a CLUTCH HEAD feature, permits of one-handed driving. A simple reverse turn of the screw in the recess locks screw and bit as a unit.

The savings of CLUTCH HEAD *Screws for every assembly operation will be self-evident when you personally examine them. We invite you to send for package assortment of Sheet Metal, Thread-forming, and Machine Screws, sample Type "A" Bit, and illustrated Brochure.*

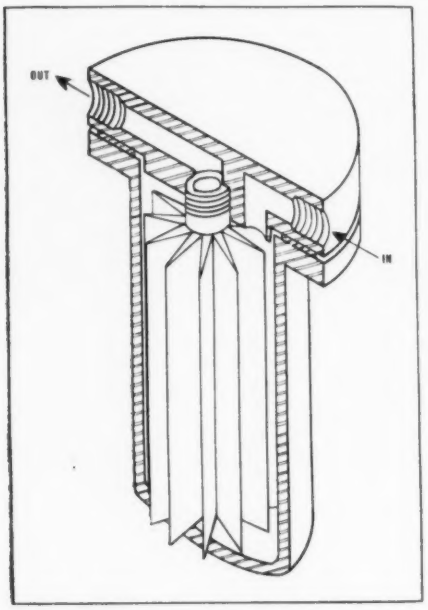
CLUTCH HEAD SCREWS

"America's Most Modern Screw"

UNITED SCREW AND BOLT CORPORATION

CLEVELAND 2 CHICAGO 8 NEW YORK 7

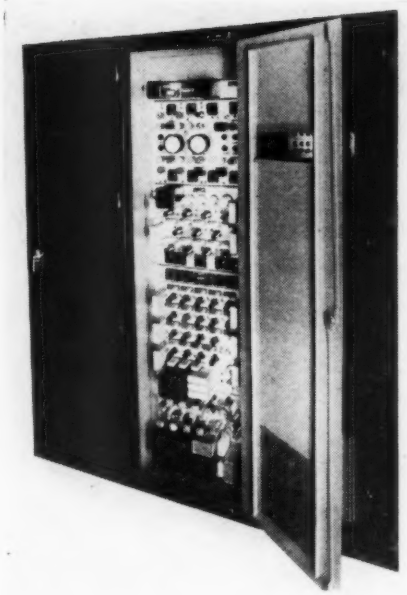
time is less than one cycle. Silver alloy contact tips reduce deterioration due to oxidation, and assure long tip life and low contact resistance. Interchangeable dual magnetic trips have accurate "sealed in" liquid-displacement time-delay devices using non-sludging silicone fluid. The AK-1 is suitable for "selective tripping" systems because of the accuracy and coordinated characteristics of the trip units. Access to all accessories is from the front of the breaker which can be supplied either for individual mounting or as an integral part of draw-out switchgear equipments. It is available for electrical or manual operation.



In-Line Filters

Micro Metallic Corp., 193 Bradford St., Brooklyn 7, N. Y.

Three basic types of porous stainless steel element can be used with "in-line" filters. Range of filtration is from 20 to 65 microns and filter areas vary from 18 sq in. to 24 sq feet. Strainless steel filter bodies are built for 200 psi pressures but specially reinforced units are available for greater pressures. The star-type element, illustrated, is used in the larger assemblies to provide maximum area for "clarification" and "polishing" installations. Bayonet shaped elements provide maximum space for solids collection and are designed for a 100 psi pressure differential. Cylindrical elements are more suitable for low pressure differentials and small amounts of solids collection. Bodies are threaded to fit $\frac{1}{4}$ to $1\frac{1}{2}$ in. standard pipe sizes.



Signal Generator

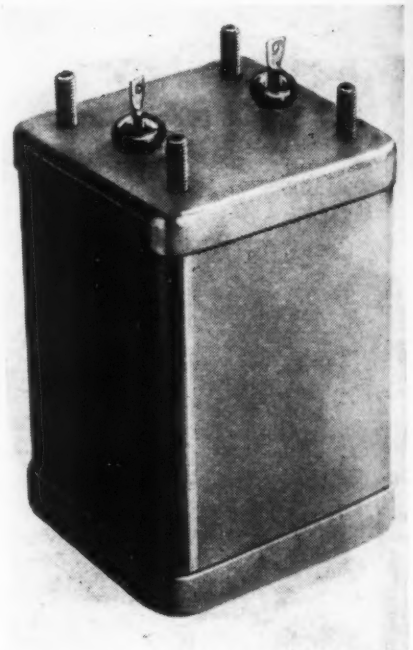
Allen B. DuMont Labs., Inc., 42 Harding Ave., Clifton, N. J.

Model TA-107 A/B synchronizing signal generator conforms to all RMA and FCC specifications for standard output signals, horizontal and vertical driving signals, composite video blanking and synchronizing signal. Linearity test signals at 900 cycles provide 15 horizontal bars, while 157.5 kc signals provide 10 vertical bars mixed with blanking for use in checking scanning linearity of picture monitors and television receivers. Bars appear on two 3 in. cathode-ray tubes used in switchless, simultaneous monitoring of all frequencies in the generator. Frequency counts can therefore be checked or adjusted without use of external oscillographs. Leading edges of equalizing pulses are also leading edges of horizontal and vertical pulses, thus insuring perfect interlacing. A crystal oscillator at 157.5 kc, or a highly stable self-exciter oscillator, can be selected by a switch for use as master oscillator. The self-excited master oscillator is useful for synchronizing the generator, by means of the provided lock-in circuit, to the 60 cycle power line or to a remotely generated synchronizing signal. The equipment is used for furnishing horizontal and vertical driving pulses, blanking signals, and composite synchronizing signals required by studio and film cameras, camera control units, monitors and other telecasting station equipment. Cabinet dimensions are $83\frac{1}{4}$ x 22 x $18\frac{1}{4}$ in.; power consumption is 680 watts.

Capacitor Insulating Paper

General Electric Co., Schenectady 5, N. Y.

A low-loss Kraft paper has raised the ceiling rating for large power factor capacities to 25-kvar, ten kilovars higher than the practical design limit that has stood for 15 years. This 67 percent increase in capacity is possible because the new paper has a 20 percent lower temperature rise than the dielectric previously used. Tests revealed that the temperature rise of a 15-kvar capacitor with standard paper and a 25-kvar unit with the new paper agreed within 3 percent at the maximum allowable operating condition of 135 percent of rating. The increased unit capacity permits the application of higher kilovars at the pole top. A total of 225-kvar can be mounted on a single pair of cross arms as compared with a 180-kvar limit when using 15-kvar capacitors. Units are of the individual pole-type, for use in primary circuits carrying from 2,400 to 13,800 volts.

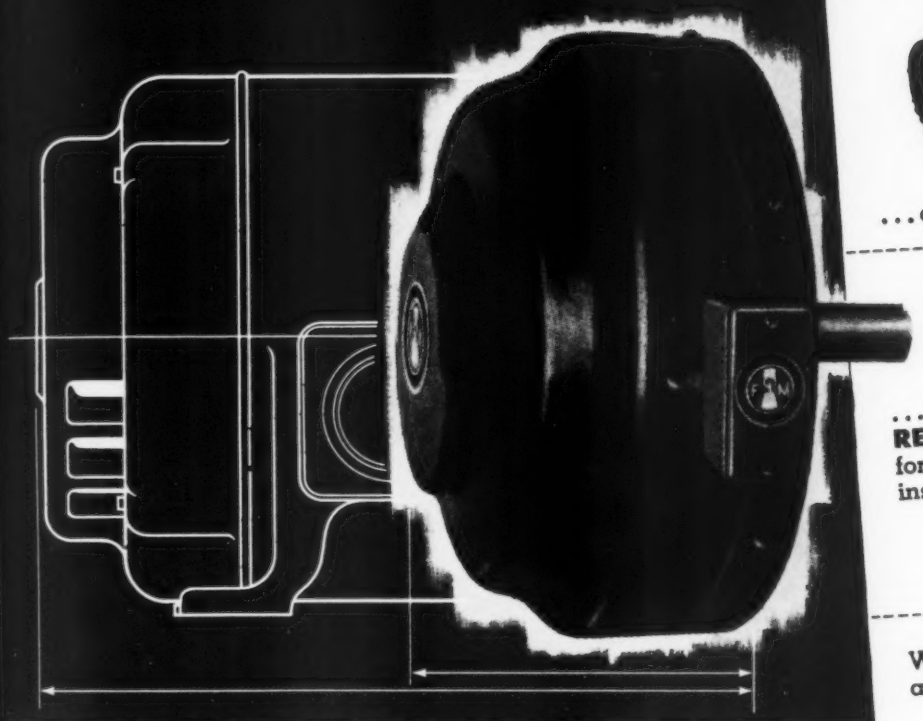


Plastic Capacitors

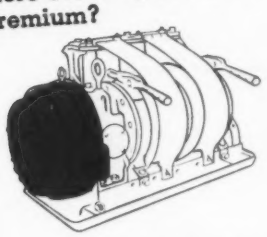
United Condenser Corp., 422 E. 138th St., New York 54, N. Y.

The dielectric hysteresis of a line of plastic capacitors is 1/10 that of similar mica insulated units. In actual laboratory tests, a one microfarad capacitor had a residual charge of 0.08 percent of an original 3000 volt charge. Hermetically- or wax-sealed assemblies are available in single or multiple units with ratings as high as

Where can You use a lighter, shorter electric motor?



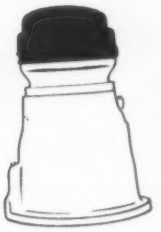
Where Floor Space is at a Premium?



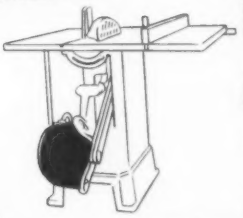
. . . as with this **SLUSHER**

Where Headroom Counts?

. . . on **GEAR REDUCERS,** for instance

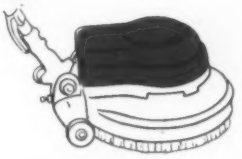


Where Weight and Space are Important?



. . . as on this **TILTING ARBOR SAW**

Where Appearance Helps to Sell?



. . . on **FLOOR POLISHING MACHINE** . . . and hundreds of other applications

FAIRBANKS-MORSE AXIAL AIR-GAP* MOTORS offer new possibilities in the application of electric power! These motors are radically advanced in design — over 30% lighter, 50% smaller than other motors of equal horsepower . . . yet they are 40-degree, standard wound squirrel-cage motors, with a range of application that is broader and more flexible than motors of conventional design. Their size, weight and design are new — their performance meets long-established Fairbanks-Morse high standards. Bulletin 2760 has full details . . . write Fairbanks, Morse & Co., Chicago 5, Ill.

**Air-Gap dimension is measured parallel to the axis of the shaft. Horizontal and vertical mountings; also, pivot base mountings. Polyphase squirrel cage and capacitor start, single phase types.*

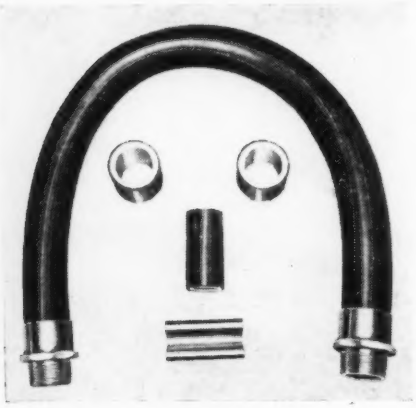
when it comes to Electric Motors . . .

FAIRBANKS-MORSE

A name worth remembering

DIESEL LOCOMOTIVES • DIESEL ENGINES • STOKERS • SCALES • MOTORS • GENERATORS
PUMPS • RAILROAD MOTOR CARS and STANDPIPES • FARM EQUIPMENT • MAGNETOS

25,000 v at 5 microfarads. Leakage resistance is 500,000 megohms per microfarad, P. F. is 0.05 to 0.1 percent, and continuous operation is satisfactory at temperatures up to 65 Centigrade.



Synthetic Resin Hose

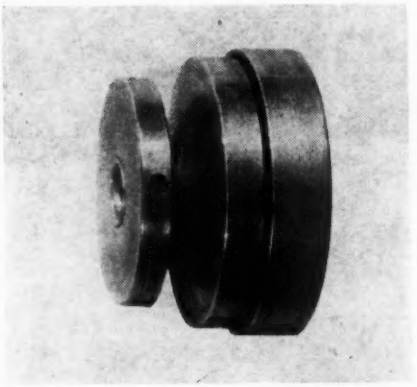
Resistoflex Corp., Belleville, N. J.

Compar tube stock in sizes up to 1½ in. ID for conducting hard-to-handle solvents and gases is available in various constructions. The synthetic resin is unaffected by aromatic hydrocarbons, chlorinated solvents, insecticides and the ester group, in addition to fuels, oils, petroleum spirits, naphtha, ether and carbon disulphide. Refrigerants such as freon 12 and 22 and methylchloride can also be safety conducted by this gas tight, tough, nonswelling material. The hose is supplied in bulk or with specialized assembled fittings in ten sizes from 3/16 to 1½ in. ID. Small sizes carry working pressures to 1,500 psi while the larger ones are rated at 125 psi working pressure. Constructions include a woven carcass with wire insert for sizes from ¾ in. up and various braided carcasses for all sizes with or without static wire.

Fire and Smoke Detector

Mine Safety Appliance Co., Pittsburgh 8, Pa.

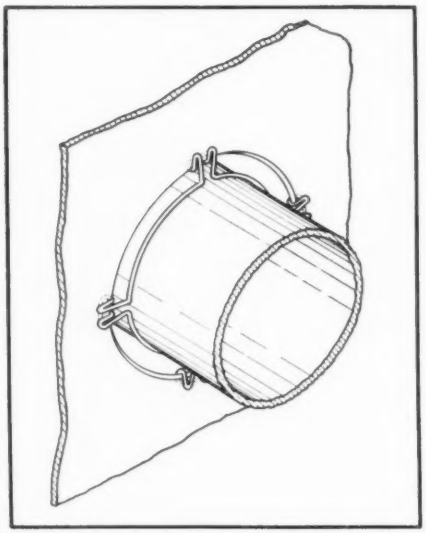
Approved by CAA for use in the cargo and luggage compartments of transport aircraft, the MSA Carbon Monoxide and Fire Detector is insensitive to false alarms caused by voltage variations, dust and atmospheric conditions. The instrument is sensitive to excessive carbon monoxide contained in the surrounding air. Samples of air are drawn into the unit and analyzed. If dangerous concentrations of the gas are present, warnings are indicated by a system of lights on the pilot's instrument panel.



Automatic Clutch Pulley

W.S.K., Inc., Donovan Bldg., Detroit 1, Mich.

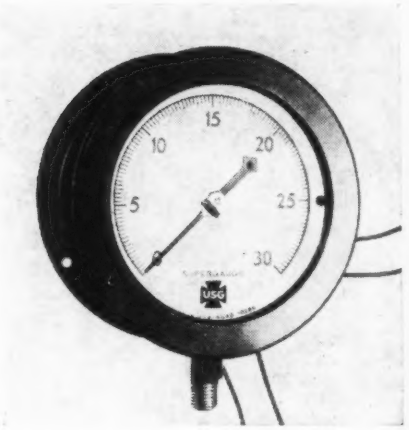
Movement of the center floating cone automatically compensates for stretch and wear of belts running in this reversible, variable pitch diameter clutch pulley. Normally the mechanism is set to engage at 1,400 rpm under no load and at 1,700 rpm under full load, but adjustments can be made during manufacture for special requirements. The combination of clutch and variable pitch diameter permits economical motor starting and provides a high starting torque. It is not necessary to change the center to center distance between pulleys to install or remove a belt. Eight types of pulley with ⅝, ¾ or 1 in. bores are available. Keyway and locking set screw are provided.



Hose Mounting Clip

Pepka Spring Co., 810 S. Waugh St., Kokomo, Ind.

Easily installed and removed, the simple wire clip provides a shock-resisting, non-chafing mount for hoses, ducts and tubes in structural apertures. Invented by shop personnel of Glenn L. Martin Co., the clip is made from a continuous piece of cold drawn music wire. About 13 in. of wire are needed for supporting a 2 in. OD hose or duct. The spring action of the ring against the hose and the four grippers against the edges of the aperture provides ample pressure for permanent support.



Pressure Switches

U. S. Gauge Div., American Machine and Metals, Inc., Sellersville, Pa.

The switching differential of Type VI pressure switches is only 3 percent of the full scale reading. This line of regulators is rated at 10 amp, 125 v a-c and covers the range from 30 in. vacuum to 10,000 psi. An extra Bourdon spring is connected internally to the alarm spring to actuate a conventional type indicator. This permits an accurate indication of the pressure being controlled while remaining entirely independent of the setting at the electrical contacts. In this way pointer lag does not disrupt the accuracy of the alarm contacts. Alarm position is easily set with a screw driver.

Vinyl-Coated Fabrics

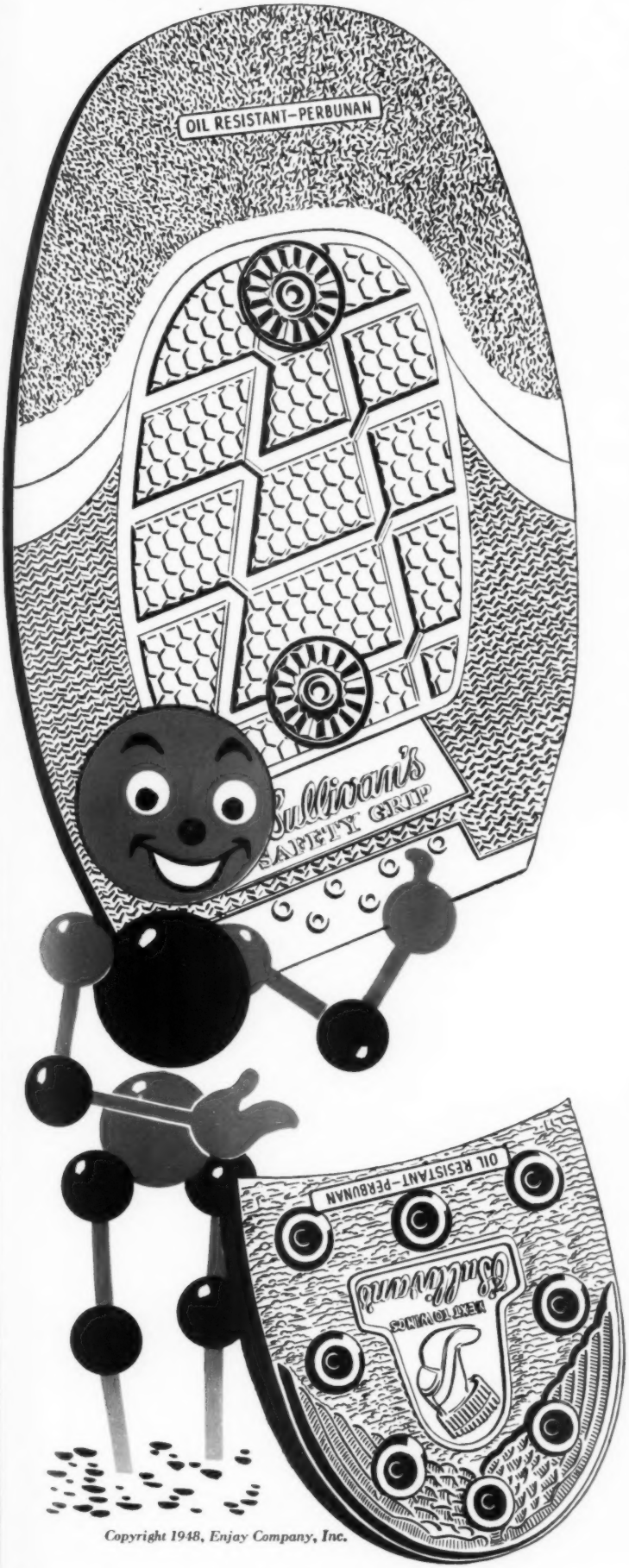
American Brattice Cloth Corp., Warsaw, Ind.

Several types of vinyl-plastic treated fabrics are available for industrial applications. One type has a jute base and another a cotton duck base. Both fabrics are thoroughly impregnated and coated on both sides. They are flameproof, mildew proof, impervious to moisture and highly resistant to abrasive wear, creasing, flexing and puncturing. In addition to standard sheets and rolls of various widths, the materials are available in troughs, tubing and hydraulic piston covers.

O'Sullivan —— *"America's No. 1 Heel and Sole"*

selects

PERBUNAN



BECAUSE *"We tried every oil resistant material available and we found Perbunan could be finished to the right degree of hardness and still have sufficient high and low temperature flex resistance in presence of oil" . . . writes J. M. Mason, Vice President, O'Sullivan Rubber Corporation.*

BECAUSE with this new O'Sullivan line, working shoes can now have heels and soles that gasoline and oil *cannot penetrate*—as happens with leather.

BECAUSE Perbunan Nitrile Rubber will not deteriorate or swell after contact with gasoline or oil—as happens with natural rubber.

BECAUSE Perbunan heels and soles keep their safety-grip qualities *longer* than natural rubber.

IF YOU have problems that could be solved by a rubber that not only resists oil, weather extremes, abrasions and wear . . . but also *holds* delicate colors—write our nearest office!

PERBUNAN
REG. U. S. PAT. OFF.

THE RUBBER THAT RESISTS OIL, COLD, HEAT AND TIME

ENJAY COMPANY, INC., 15 West 51st Street, New York 19, N. Y.; First National Tower, 106 South Main Street, Akron 8, Ohio; 221 North La Salle St., Chicago 1, Illinois; 378 Stuart Street, Boston, 17, Massachusetts. West Coast Representatives: H. M. Royal Inc., 4814 Loma Vista Avenue, Los Angeles 11, California. Warehouse stocks in Elizabeth, New Jersey; Los Angeles, California; Chicago, Illinois; Akron, Ohio; and Baton Rouge, La.

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"FREEZING" is expensive

WHERE BASIC DESIGNS IN ELECTRIC CONTROLS ARE RESULT-ENGINEERED FOR YOU

Unique design and spring suspension prevent it in this Ward Leonard Relay

The generous wipe imparted to the contacts of Ward Leonard Heavy Duty (105) Relay by its unique design and spring suspension, results in freedom from contact "freezing" or welding.

This mighty midget will perform motor starting functions ordinarily assigned to larger relays.

Ward Leonard relays are "Result-Engineered". By modifying a basic design, Ward Leonard can give you the results of a special . . . for the price of a standard.

Write for Relay Catalog. Ward Leonard Electric Co., 63 South Street, Mount Vernon, N. Y. Offices in principal cities of U. S. and Canada.

WARD LEONARD ELECTRIC COMPANY

RESISTORS · RHEOSTATS · RELAYS · CONTROL DEVICES

NEW BOOKS

Theory of Limit Design

J. A. VAN DEN BROEK, *Professor of Engineering Mechanics, University of Michigan.* 144 *pages,* $5\frac{3}{4}$ x $8\frac{1}{2}$ *in. Published by John Wiley & Sons, Inc., 440 Fourth Ave., New York* 16, *N. Y.* $3.50.

Shall engineering design be for permissible safe stresses or permissible safe deformations? The latter argument is the thesis of this book. As the author emphasizes, the theory of elasticity is based on conditions that are rarely true: (1) elastic behavior, (2) elastic stress distribution. Limit design, on the other hand, presupposes ductile or semiductile material; therefore, stress values and stress distribution within the elastic limit are of little use. Conventional design also assumes freedom from scratches or surface imperfections, freedom from residual stresses and perfect alignment of loads. These three assumptions are scarcely ever true. Furthermore, in cold forming the elastic limit is continually exceeded. Why, therefore, should engineers use a theory based on so many known erroneous conditions? Deformations are the design objective, not the stress value.

Professor Van Den Broek is admittedly an enthusiast for the cause of teaching design in terms of deformations within the given structure. His book is an excellent presentation of the philosophy and basic theory of limit design.

Opening chapter discusses the physical properties of metals in terms of of their significance to strain and strength. Chapter 2 covers the limit design of simple structures such as tension bars, rivet connections, simple cantilevers, and springs. Limit design of statically indeterminant (redundant) structures such as the built-in beam is covered in Chapter 3, emphasizing the difference between beams of aluminum and magnesium and steel; differences based on gradually varying vs. abruptly varying stress-strain curves and comparative brittleness. Limit design of trusses is covered in Chapter 4 and connections are discussed in Chapter 5.

While the theory is perfectly valid for the machine design field, illustrations and applications are drawn from the civil engineer's large structures, such as transmission towers. It is hoped that a similar text will be written with strong emphasis on the design of machine elements; where the structural members have a greater variety of

shapes and more complex arrangements. Such a book is badly needed to synthesize the results of practical machine design and experimental stress analysis; and it could be incorporated with great benefit in most mechanical engineering courses.

Practical Descriptive Geometry

S. E. RUSINOFF, *Associate Professor of Mechanical Engineering, Illinois Institute of Technology.* 259 *pages,* 5½ x 8¼ *in. Published by American Technical Society, Drexel Avenue at 58th Street, Chicago* 37, *Ill.* $3.50.

This textbook deals with the practical application of the principles of descriptive geometry to shop and drafting room layout practice.

A condensed review of engineering drafting is presented and the principles of projection explained. Then chapters follow that cover point, line, and plane problems; intersection of planes, curved lines and surfaces; development of curved lines and surfaces; intersection of planes, curved lines and surfaces; development of curved surfaces; intersection of surfaces; and solutions of miscellaneous force and vector problems by the use of descriptive geometry.

Representative problems are taken from many industrial fields that include the automotive, machine tool, aviation and steel.

Television Vol. III and Vol. IV

VOL. III, 486 *pages;* VOL. IV, 510 *pages; each volume,* 6 x 9¼ *in. First two post-war volumes of Technical Book Series published by RCA Review, Radio Corporation of America, Princeton, New Jersey. Price of each volume: Clothboard covers* $2.50; *paper covers,* $1.50.

The two volumes present compilation of selected complete and summarized papers on television during 1938-1946. Vol. III (1938-1941) groups the papers in four sections: Pickup, Transmission, Reception, and General. Vol. IV (1942-1946), uses these same groupings plus sections on color television and Military Television; also includes bibliography of technical papers by RCA authors, 1929-1946.

The Color of Life

ARTHUR G. ABBOTT. *First edition.* 294 *pages,* 9 x 6 *in. Published by the McGraw-Hill Book Co.,* 330 *W. 42nd St., New York* 18, *N. Y.* $6.

A complete text on the nature, production and uses of color. The book is written for the laymen but contains much fundamental and practical application data about color. Both the

FLEXIBLE
yet sturdy

Ward Leonard Edgeohm High Current Resistors for intermittent or continuous duty

Flexible in range, current and size, Ward Leonard Edgeohm Resistors are used in single or multiple assemblies. They are used for intermittent duty in motor starting, field discharge and dynamic braking in d-c controllers, and for continuous duty in high current battery charging rheostats, load banks, plating and welding.

Ward Leonard resistors are "Result-Engineered". By modifying a basic design, Ward Leonard can often give you the results of a special . . . for the price of a standard.

Write for Resistor Catalog. Ward Leonard Electric Co., 63 South Street, Mount Vernon, N. Y. Offices in principal cities of U. S. and Canada.

WHERE BASIC DESIGNS IN ELECTRIC CONTROLS ARE RESULT-ENGINEERED FOR YOU

WARD LEONARD
ELECTRIC COMPANY
RESISTORS · RHEOSTATS · RELAYS · CONTROL DEVICES

SHORT on STEEL?

NICKELOID METALS MAY BE THE ANSWER

Why fight the steel shortage when it comes to bright metal for decorative or functional use? Nickeloid Metals offer ready availability of bright chrome or nickel plated finishes on base metals of brass, zinc, or copper — quality metals, yet no insurmountable cost premium. If you now use steel and plate or finish the parts in your own plant, there are important savings in the use of Nickeloid Metals. They simplify the whole manufacturing cycle: just stamp or form . . . then assemble. Available in protective Mar-Not coating; in flat sheets or coils; bright or satin finish or patterns; many gauges and tempers. Ask our representative to call.

Free New Booklet Tells **USES for NICKELOID METALS**

This colorful illustrated booklet tells many of the ingenious ways in which manufacturers are using Nickeloid Metals to improve the appearance and marketability of their products. Write for it on your company letterhead.

50 Years of Pre-plated Metal Leadership

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esthetic and physical effects of color are covered; together with application data showing how these effects have been used in agriculture, manufacturing, selling and advertising. The author has drawn on a great number of colorists and also manufacturers of paints, pigments, dye, ink, etc., for his material.

Rempe Engineering Data Book

ARTHUR G. VOGEL. *34 pages,* $8\frac{1}{2}$ x 11 *in. Published by Rempe Co., 340 N. Sacramento Blvd., Chicago 12, Ill.* $1.50.

A reference manual for design engineers and draftsmen who design pipe coils and fin coils. Data is included on dimensional limitations, coil development formulas and heat transfer factors.

It is profusely illustrated with photographs and line drawings showing applications for different types of coil design. With each type of design is included a chart which indicates the specifications that the designer has to supply to the manufacturer. Material specification data and tables of various pipe sizes and heat transfer coefficients are included.

Mallory Vibrator Data Book

FUNDAMENTAL PRINCIPLES *of vibrator power supply design. First edition. 135 pages, 64 charts and diagrams, 6 x 9 in. Compiled and published by P. R. Mallory & Company, Inc., 3029 E. Washington St., Indianapolis 6, Ind.* $1.

Data book is directed at engineers who use and apply small d-c powered equipment, such as auto radios. It describes basic structures, circuits, operating characteristics, and inspection procedures.

The 12 chapters include discussion of: Preliminary design; selection factors; transformer characteristics; timing capacitors; power supply circuits; interference elimination; and 16 pages of tables, charts, graphs and formulas. Loose leaf data sheets on vibrator characteristics are included with copies of the Data Book ordered by manufacturers' engineers.

Shot Peening

PUBLISHED *by American Wheelabrator and Equipment Corp., Mishawaka, Ind., 181 pages, 6 x 9 in.* $1.50.

This book covers all phases of the process of shot peening including detailed discussions of the engineering advantages in addition to a description of the methods used in shot peening and their control.

Part one has chapters describing the

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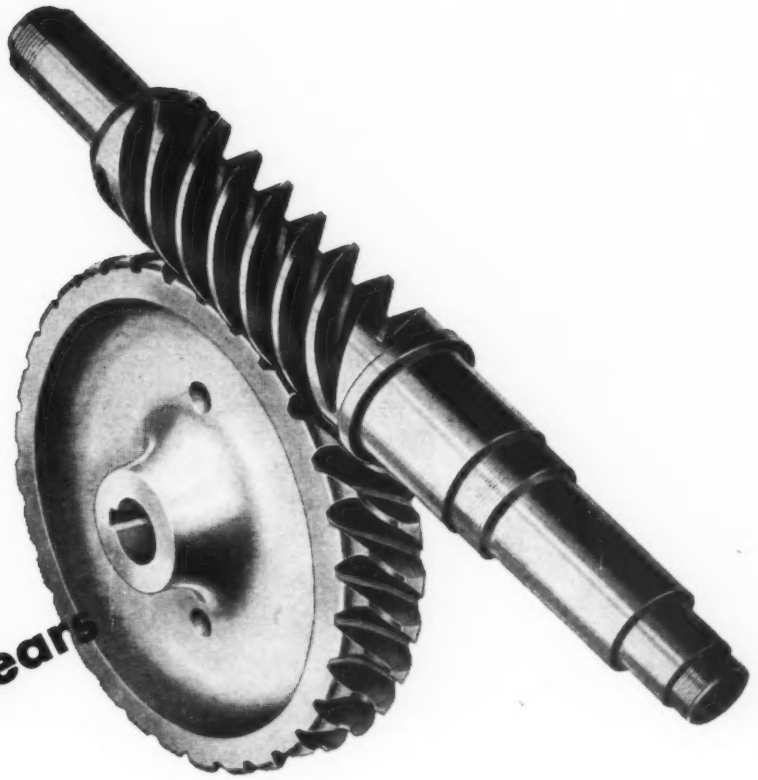

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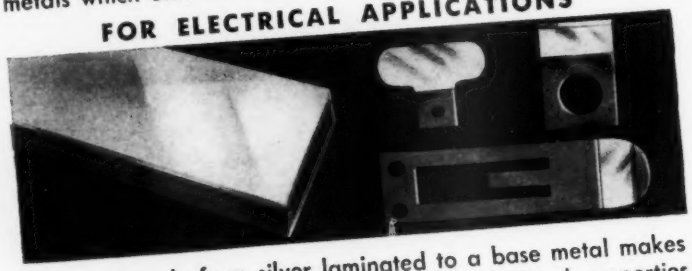

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process of shot peening, its benefits and the methods and the equipment used in the manufacturing process.

Part two, written by Prof. H. F. Moore, is entitled "Strengthening Metal Parts by Shot Peening." Part three, by J. O. Almen, is entitled "Improving Fatigue Strength of Machine Parts." Part four, by O. J. Horger, is entitled, "Mechanical and Metallurgical Advantages of Shot Peening."

The book will serve as a reference and guide for all engineering and manufacturing personnel who specify and produce shot peened parts.

Pressure Vessels for Industry

HARRY M. SPRING, JR., *Commissioned Boiler Inspector.* 259 *pages,* 5½ x 8 *in. Published by McGraw-Hill Book Company, Inc.,* 330 *W.* 42*nd St., New York* 18, *N. Y.* $3.50.

Engineers engaged in building, installing and maintaining many types of pressure vessels will find this book a valuable reference.

Pressure vessels used in many industries are described. Fields covered are: Compressed air systems, steam and hot water services, pulp and paper mills, rubber industry, textile industry, chemical industry, and specialized services. Chapters also cover: Pressure and stress calculations, construction and fabrication practices, appliances for pressure vessels, and defects. An appendix of reference and working data is included.

Rome Cable Manual

Published By Rome Cable Corporation, Rome, N. Y. 250 *pages,* 5½ x 7¾. $2.50.

A pocket size manual of technical information tables, data, and calculations for engineers concerned with the application of wire and cable.

The manual includes: Wire and cable technical tables, engineering calculations, audio and radio frequency wire and cable data, National Electrical Code data, properties of materials, mathematical tables, conversion tables, general technical information.

Control Charts

EDWARD S. SMITH, *Professor of Mathematics, University of Cincinnati.* 158 *pages,* 6 x 9 *in. Published by McGraw-Hill Book Co., Inc.,* 330 *W.* 42*nd St., New York* 18, *N. Y.* $3.

Designed for the busy executive in industry, this book provides a simplified semi-mathematical introduction to charts of statistical quality control covering their construction, interpretation and practical application. Control charts for averages, ranges, fraction de-

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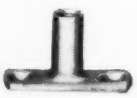

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Electronic Engineering Principles

JOHN D. RYDER, *Ph.D., Professor of Electrical Engineering, Iowa State College.* 397 *pages,* 6¼ x 9¼ *in., published by Prentice-Hall, Inc.,* 70 *Fifth Ave., New York* 11, *N. Y.* $6.65.

Textbook stresses fundamentals for understanding the electron tube as a useful engineering device. Several problems and published references are included at the end of each chapter.

The 16 chapters include: Fundamental particles; electron ballistics; emission characteristics; diode rectifiers; vacuum triode; multi-element tubes; amplifiers; gas diodes; gas control tubes and circuits; and photoelectric cells.

Steel and Its Heat Treatment, Volumes I and II

D. K. BULLENS *and The Metallurgical Staff of Battelle Memorial Institute. Fifth Edition. Vol. I:* 489 *pages; Vol. II:* 293 *pages.* 6 x 9¼ *in. Published by John Wiley & Sons, Inc.,* 440 *Fourth Ave., New York* 16, *N. Y.* $6.00; $4.00.

In 1916 the Battelle metallurgists wrote the first edition of this book to link together the theoretical and practical aspects of steel and its heat treatment. This 5th edition appears in three volumes: Vol I concerns definitions, terminology, and fundamental concepts associated with the heat treatment of steel. Limitations and uses of tests for evaluating suitability for heat treatment, as well as the suitability of the product for engineering use, are also discussed. Vol II deals with the equipment and processes and control of heat treatment—the application of the principles described in Vol I. The third volume, yet to appear, will cover types of steels, their selection and heat treatment.

Major revision was undertaken to include the bits of new information on practice and theory that grew out

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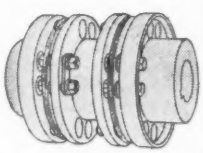

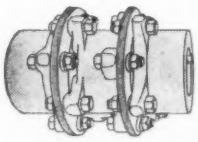

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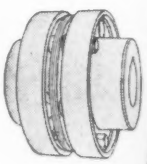

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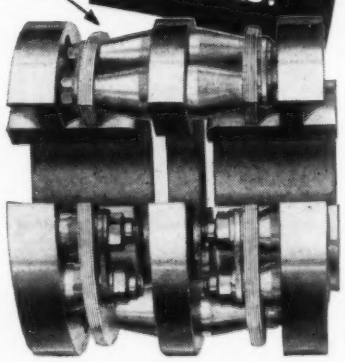

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By M. V. Caldwell, President
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Our success with the welded lower crankcase encouraged a further development shown in Figs. 3 and 4. This all-welded crankcase weighs 23 lbs. and costs only $13.76. A comparison of the original cost of $29.57 with this reduced cost of $13.76 represents an over-all production saving of 54%.

The component parts for the all-welded crankcase are fabricated from ⅛" and 3/16" sheared mild steel plate as shown in Fig. 3. The parts are clamped solidly in a universal jig for downhand welding, and then we weld inside and outside with 3/16" "Fleetweld 5" electrode using 300-amp. Lincoln "Shield-Arc" Welders.

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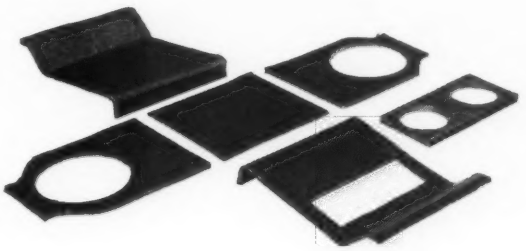
Fig. 1. Cylinder and crankcase assembly originally used. Cost $29.57.

Fig. 2. Intermediate step in welded development. Welded lower crankcase assembled to upper crankcase and cylinders.

Fig. 3. Fabricated steel parts for all-welded crankcase.



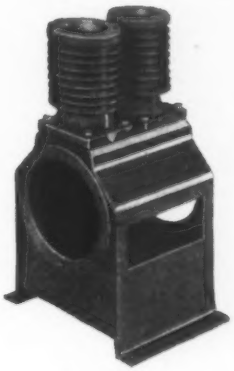


Fig. 4. Present all-welded crankcase and cylinder assembly. Cost $13.76.

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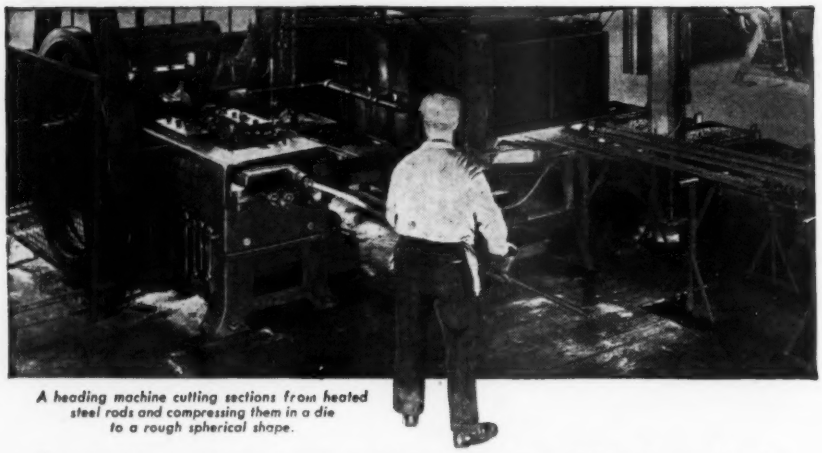

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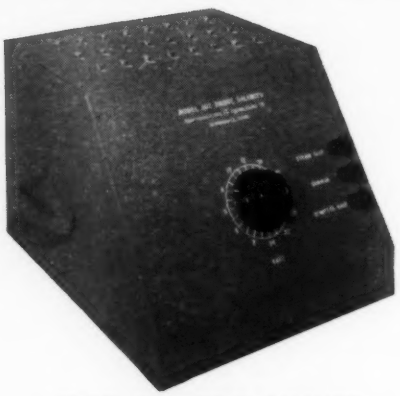

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Many parts of Vol I have the mechanical engineer's approach—"How Much Ductility Is Enough?"; effect of directional properties; conventional tests, including types of hardness testing and their correlation; stress raisers, factors in fatigue, design for limited life, local cold working; are all discussed in Chapter 6. And, incidentally, supported by a 5 page bibliography on these topics alone. Chapter 7 on impact testing is also valuable. Other useful topics in Vol I: Machinability, internal stress, "How Not to Use S Curves," stress relief annealing.

Vol II is more of a metallurgist's or production man's book, although most of the topics provide useful background for the mechanical engineer. Some subjects are flame and induction hardening, nitriding, carburizing, controlled atmospheres, heating and cooling methods. Chapter 13 on the heat treatment of cast and malleable irons, Chapter 14 on graphite and steels, and Chapter 15 on heat treatment in relation to welding and machining are especially useful.

Both volumes have many illustrations and tables, and contain excellent bibliographies to books, journals, and magazines at the end of each chapter.

Mechanics of Materials

PHILIP C. LAURSON, *Associate Professor of Civil Engineering, Yale University, and* WILLIAM J. COX, *formerly Assistant Professor of Engineering Mechanics, Yale University. Second Edition. 422 pages, 5¾ x 8½ in. Published by John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y. $4.*

This is a first text in strength of materials for undergraduates. It is simple and has been arranged so that more complicated subjects such as torsional stress and eccentrically loaded columns can be omitted or handled as separate topics. Although the authors mention the significance of stress concentration, the design engineer would wish for more emphasis on the fact that uniform stress distribution rarely occurs in machine elements.

Powder Metallurgy—Its Physics and Production

PAUL SCHWARZKOPF. *366 pages, 6 x 9 in. Published by The Macmillan Co., 60 Fifth Ave., New York, N. Y. $8.*

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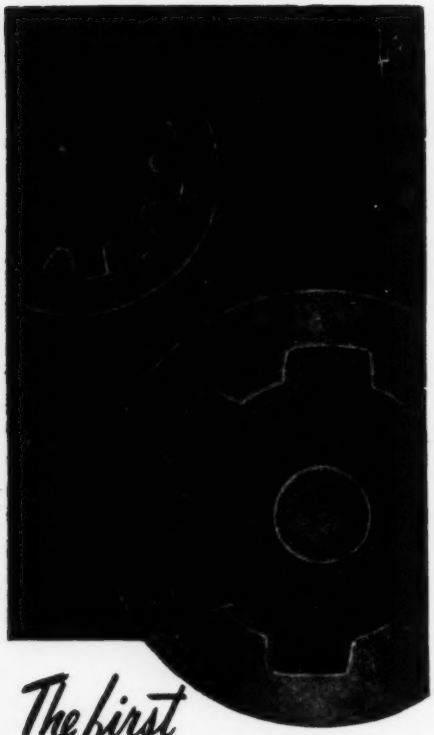

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National Electrical Code Handbook

ARTHUR L. ABBOTT. *Sixth Edition. 633 pages, 4¾ x 7 in. Published by McGraw-Hill Book Co., Inc., 330 W. 42nd St., New York 18, N. Y. $4.*

Based on the 1947 edition of the National Electrical Code, this handbook presents detailed discussions of the Code rules wherever anything of value can be contributed that will make the practical application of the rules clear and easily understandable.

The sequence of the sections and paragraphs in the Code articles has been rearranged wherever it was possible to group the rules in clearly defined subdivisions.

A key to the Code requirements, presented on the inside cover and flyleaf, forms a ready general index and shows clearly the fundamental divisions of the Code.

As a supplement to the subject index, the handbook includes a cross index for finding sections of the book that correspond to any given Code paragraph.

Industrial Management

WILLIAM R. SPRIEGEL, *Professor of Industrial Management, Northwestern University, and* RICHARD H. LANSBURGH. *Fourth Edition. 656 pages, 6¼ x 9¼ in. Published by John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y. $5.00.*

As a survey of industrial management, this text provides an adequate introduction to the many problems of the field. Discussions on Basic Management Decisions and Plant Location are followed by analysis of organization structure. Chapter 8 on Product Development and Research presents a hasty view of this aspect. Part IV on Plant and Equipment leads into sections on Motion and Time Study, Wage Payment, Buying, Selling and Transportation, Material and Production Control and Industrial Relations.

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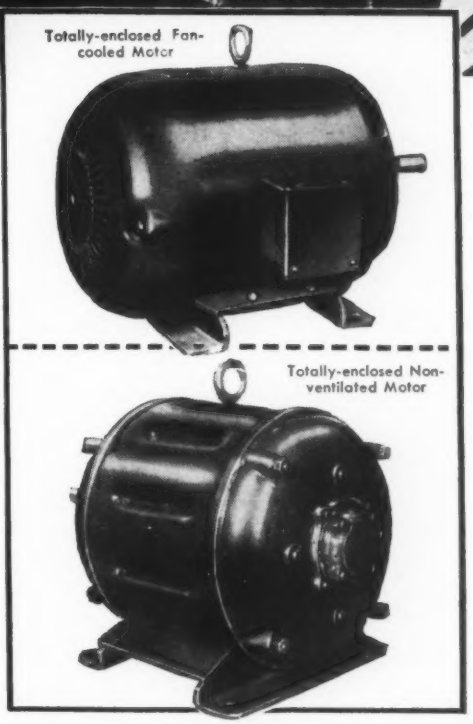

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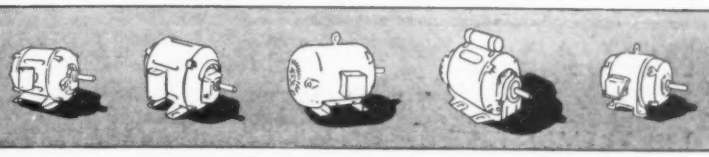

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This versatile metal forming machine was developed for use in model shops, experimental laboratories and production departments where it often replaces dies for all types of precision forming operations. Di-Acro Brakes will form a great variety of materials including bronze, stainless steel, aluminum and bi-metals.

WRITE FOR CATALOG. New edition of 40-page Di-Acro Catalog contains detailed information on all Di-Acro Brakes, Shears, and Benders and illustrates how these precision machines can be used individually or cooperatively for "DIE-LESS DUPLICATING".

◀ DI-ACRO is Pronounced "Die-Ack-Ro"

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"TEINER" offers Time and Money Savings

Metal spinning the "Teiner" way will enable you to simplify designs and speed up production. In small runs you can save the cost of expensive dies and castings.

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Stamping .... Fabricating .... Assembling .... Soldering .... Silver Brazing .... Lacquering .... Welding..etc. TEINER assures expert work in all metals and in any quantities exactly to specifications. Our engineers are ready to cooperate with you on your needs.

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130 TREMONT ST. EVERETT 99, MASS.

OUR READERS SAY

A La the Birds

To the Editor:

Enclosed is a picture of the Boeing XB-47 taken from your January issue. The caption states: "The new bomber's wings have the appearance of drooping but in flight will rise to a level higher than horizontal. . ." Somebody in your organization has been using their imagination as this statement pertaining to the B-47 is certainly incorrect.

The "droop wing" is designed into the airplane in order to improve the stability of the airplane when using sweep-back wings. With this design the effective dihedral changes so rapidly with a change in the lift coefficient that the rate of change of the rolling moment co-efficient produces instability. When straight wings are used, positive dihedral improves the lateral stability.—COLE H. MORROW
Racine, Wis.

Ed.—Our imagination did get the better of us—we regret the error.

We Like the U. S. A.

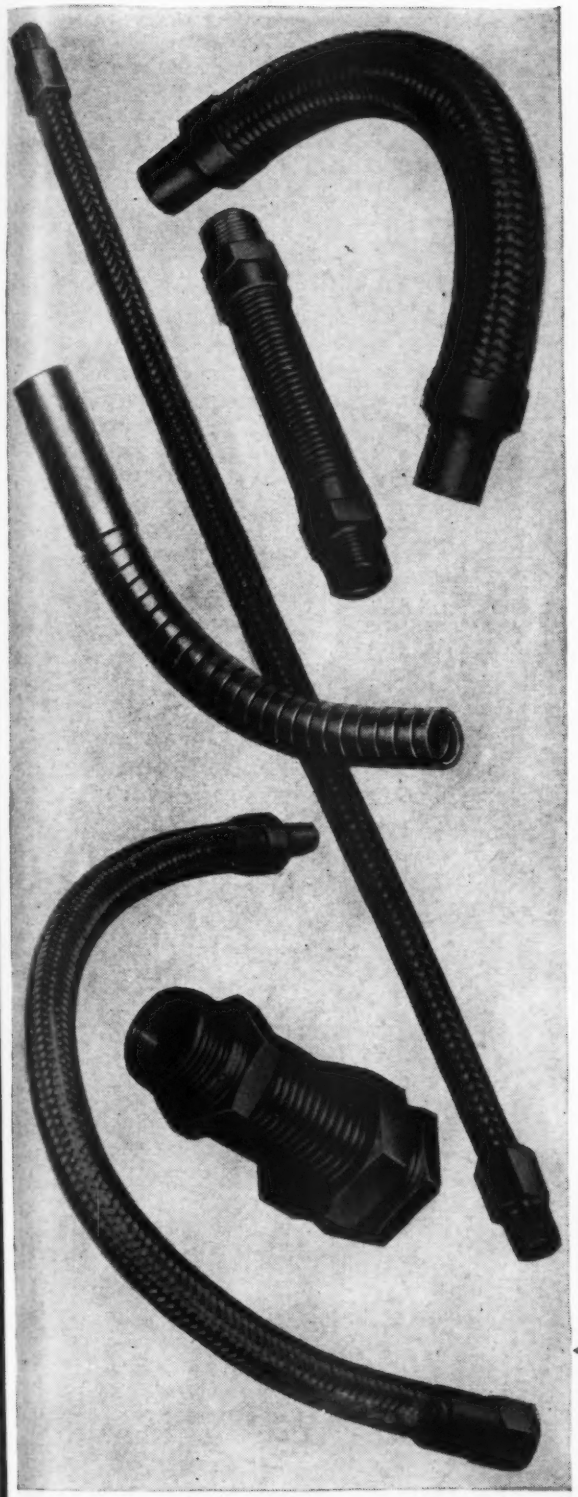
To the Editor:

Commenting on your Editorial in the January number, the first two paragraphs in which you laud the German scientists is absolute unadulterated baloney. I have yet to find evidence of any original thinking among German scientists. Why did they lose two wars?

As to our own scientific endeavors, we do not have now, and are not likely to have the contemplative atmosphere conducive to research in pure science. We have not yet learned the art of living.

Your statement that the solution does not lie solely in government sponsored pure science research leads me to comment that this is the Russian system you extol. Your statement that Russia is conducting intensive pure science research is only hearsay. You don't have the facts quite evidently. — *Signed — Anonymous*

Ed.—The gentleman did not sign his name, so we are at a loss to judge the atmosphere in which he lives. But we do want to say most emphatically that PRODUCT ENGINEERING does not



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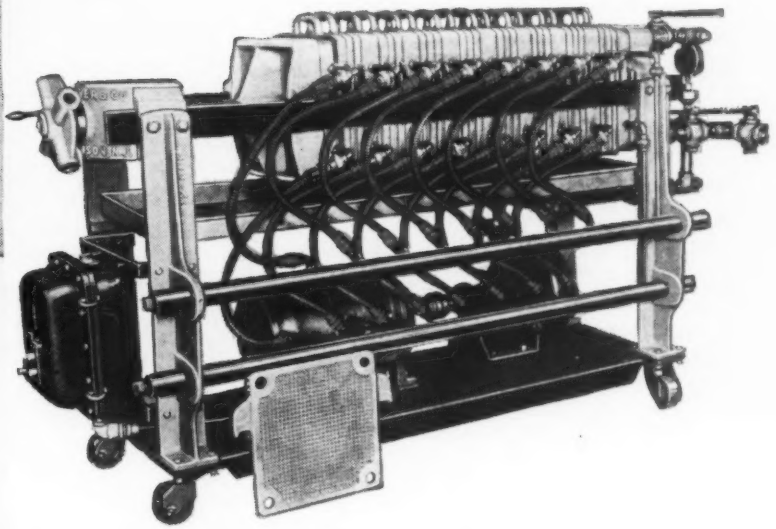
RATHER THAN EXPERIMENT with your connector problems, you can profit by submitting them to American engineers. For we have been specializing in flexible metal connector problems for forty years.

American *designs* the connector to your exact requirements—complete with special end fittings attached—at no extra cost. Whether it's conveying steam, oil, water, other liquids, semi-solids or gases, there's a type of American Flexible Metal Hose or *Seamless* Flexible Metal Tubing designed for easy installation and long life.

American Seamless Flexible Metal Tubing—made from seamless bronze tube, corrugated for maximum flexibility—is standard in sizes ⅛″ to 4″ I.D. American Metal Hose, manufactured from continuous strips of brass, bronze, aluminum, steel and other metals in four spirally wound types—with joints packed or unpacked—is available in sizes ⅛″ to 12″ I.D. Write for literature. And feel free to consult our Technical Department at any time. 48287



Filter press made by T. Shriver & Company Inc., Harrison, New Jersey. Steam lines are ½″ I.D. Seamless Flexible Bronze Tubing—designed by American.

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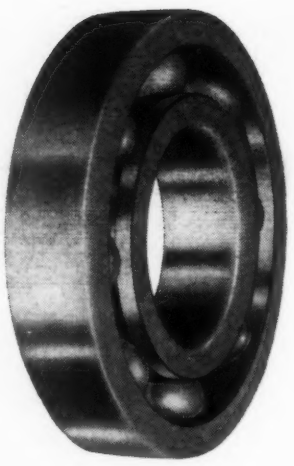
You've often remarked that no piece of equipment can be superior to its component parts...

You appreciate the broad recognition and acceptance of BCA Ball Bearings in industry...

You know you can tell your engineers to draw upon our half-century of experience in friction control practices, encompassing many varied fields of industry...

You, who insist upon continuous, full-capacity, trouble-free operation, know this can be assured by specifying BCA Ball Bearings.



BEARINGS COMPANY OF AMERICA
LANCASTER, PENNSYLVANIA

BCA RADIAL • ANGULAR CONTACT • THRUST BALL BEARINGS

extol the Russian system and we believe that our Russian and European correspondents send us information, not hearsay. Perhaps we have not yet learned the art of living, but the good old U.S.A. still has the best living of any spot on earth, for which we are duly thankful.

Model Operator

To the Editor:

A number of references have appeared in your valued publication concerning machine models to be used in laying out production plants and also to be photographed in their working relationship to give customers an idea of some special arrangements.

May I have the names of firms specializing in the manufacture of such models.

—NICHOLAS MONSARRAT
Pantex Mfg. Corp.
Pawtucket, R. I.

Ed.—Here are a few:

John Hill Layouts, Mount Clemens, Mich. (Plexiglas Magne-Plastic machinery templets)

Models Inc., North Bergen, N. J. (Technical models)

Monroe Miniature Modelers, Monroe, Mich. (Factory layouts)

Stark Industrial Models, 95 Jane St., New York 14, N. Y.

"Visual" Planning Equipment Co., 6247 Broad St., Pittsburgh 6, Pa. (3-dimensional planning equipment)

What's the Whole Story?

To the Editor:

There was mention in the Progress in Review section of an aluminum solder known as Alsoco.

We would like to know who tested the solder, who is selling or manufacturing it and any additional information that you might have on this subject.—J. W. PRYOR, *Surface Combustion Corp.*

Ed.—Drop a line to Alsoco Corp., 10 E. 52nd St., New York, N. Y. They have the dope.

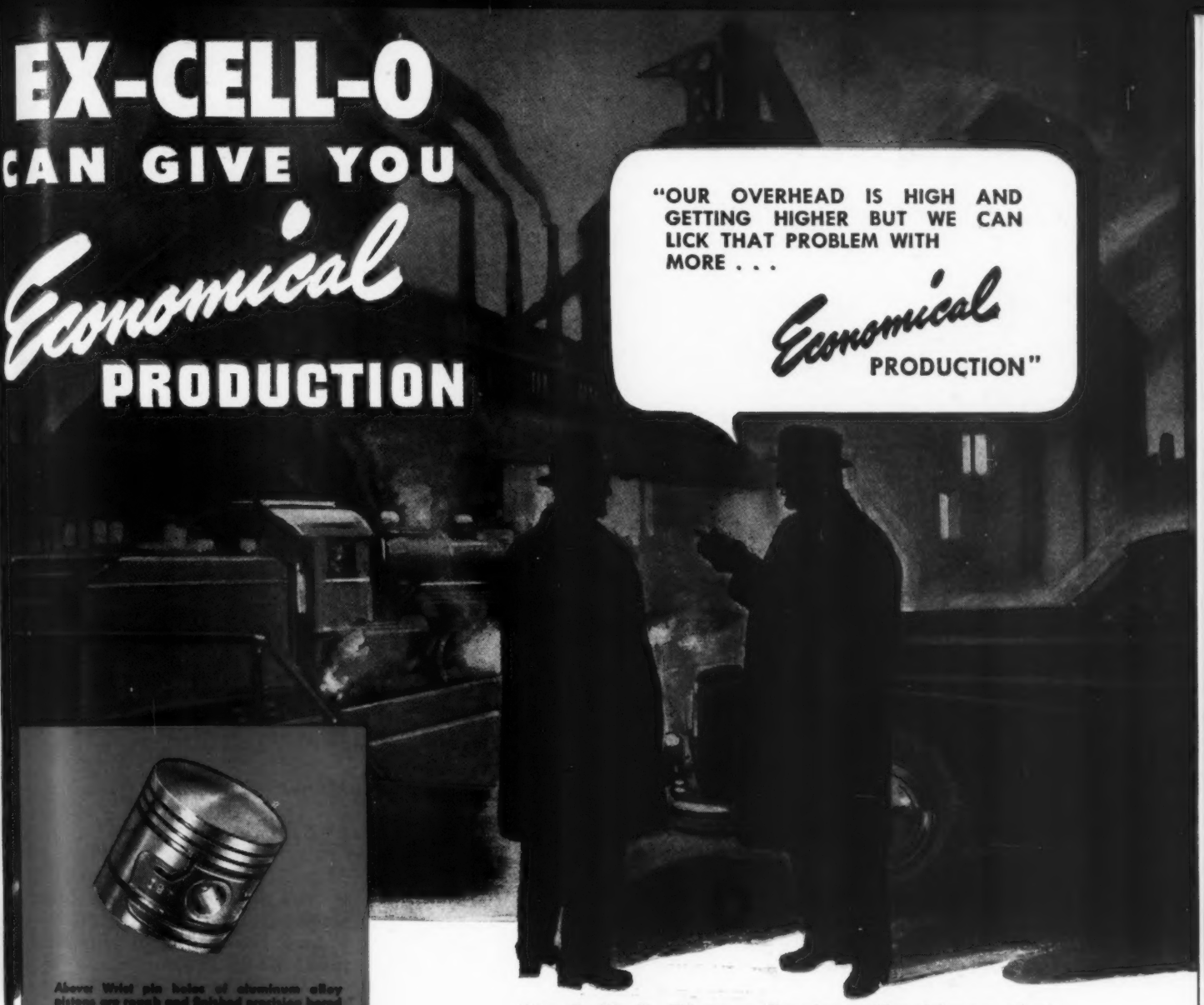
Submersible Motor-Pump

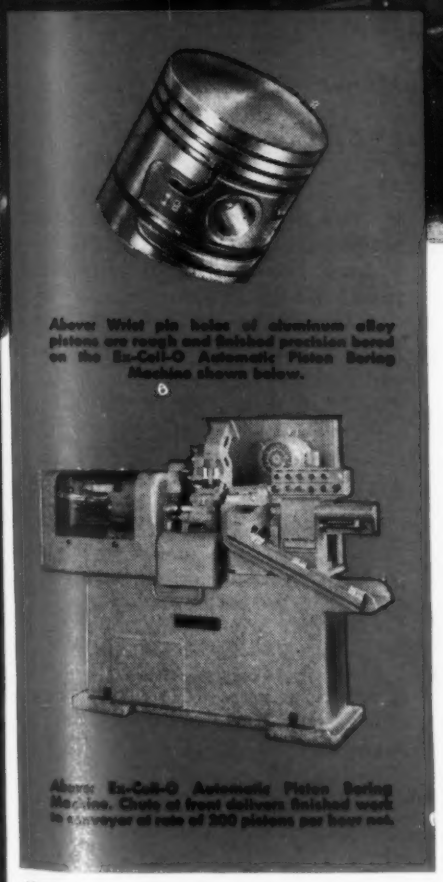
To the Editor:

In our plant we require a motor driven pump unit which can be submersed, motor and all. We recall a reference to such equipment in your publication but are unable to locate the information.

We would appreciate your for-

EX-CELL-O CAN GIVE YOU *Economical* PRODUCTION





Above: Wrist pin holes of aluminum alloy pistons are rough and finished precision bored on the Ex-Cell-O Automatic Piston Boring Machine shown below.

Above: Ex-Cell-O Automatic Piston Boring Machine. Chute at front delivers finished work to conveyor at rate of 200 pistons per hour net.

48-16

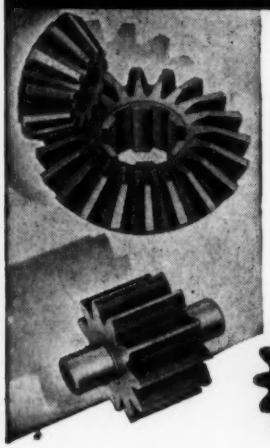
Ex-Cell-O Piston Boring Machines Cut Unit Costs with Fully Automatic Operation

One solution to the problem of rising labor and material costs is through the use of more automatic machinery. For instance, the Ex-Cell-O Piston Boring Machine shown to the left provides an excellent illustration of how automatic operation increases output per manhour. The pistons are fed into the machine from a chute, and after being rough and finish bored they are ejected onto a conveyor belt *at a rate of 200 pistons per hour net!* Pistons come to the machine with the wrist pin holes just as they are cast—no previous operations on them are necessary. The operator's only function is to load the work into the chute and spot check the finished parts. In many instances, one man can take care of several machines.

EX-CELL-O CORPORATION

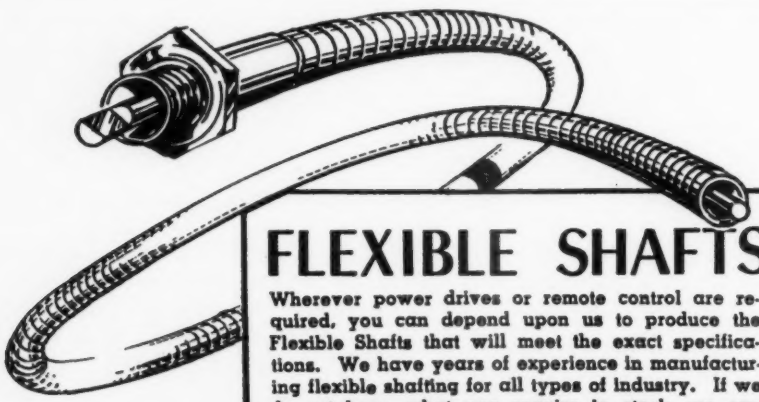
DETROIT 6, MICHIGAN

Special Multiple Way-Type Precision Boring Machines • Special Multiple Precision Drilling Machines • Precision Boring, Turning, and Facing Machines, and Fixtures • Precision Cylinder Boring Machines • Precision Thread Grinding Machines • Precision Lapping Machines • Precision Broach Sharpening Machines • Other Special Purpose Machines • Tool Grinders • Continental Cutting Tools • Broaches, Broach Fixtures and Broach Grinders • Counterbore Sets • Grinding Spindles • Hydraulic Power Units • Textile Spindles • Drill Jig Bushings • R.R. Pins and Bushings • Fuel Injection Equipment • Dairy Equipment • Aircraft and Miscellaneous Production Parts



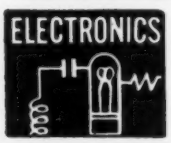
Spur—bevel—spiral—zerol—worms and worm gears—racks—sprockets. All are precision cut on up-to-the-minute equipment exactly to your specifications. *Prompt quotation upon receipt of your sample or blueprint.*

E. B. SEWALL MANUFACTURING CO.
696 Glendale St. St. Paul 4, Minn.



FLEXIBLE SHAFTS

Wherever power drives or remote control are required, you can depend upon us to produce the Flexible Shafts that will meet the exact specifications. We have years of experience in manufacturing flexible shafting for all types of industry. If we do not have what you require in stock, we can make shafts to your specifications. Our engineers will be glad to work out your problems without obligation.



Many new uses for flexible shafts that carry power around any corner have been developed by our engineers . . . in machine shops, electronic, automotive, aircraft, in all industries where power drives or remote control are required. *Write for Manual P. E.*

CIRCLE

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4311-13 RAVENSWOOD AVE. CHICAGO 13, ILL.
WEST COAST BRANCH: 431 Venice Blvd.; Los Angeles 15, Cal.

warding the name and address of the manufacturer and any additional information you might have on this subject.—C. O. SCHUPP, *Supervising Engineer*
The George T. Stagg Co.
Frankfort, Ky.

Ed.—The article "Submersible Pump Has Fluid Primer," PRODUCT ENGINEERING, January 1948, page 108, is the one you recall. This pump was developed by Worthington-Simpson Ltd., London, England. Byron Jackson Co., E. Slauson & Thomas Aves., Los Angeles, Calif., make similar equipment.

Plastic Belting

Numerous requests have been received for additional information about Fuse-ite plastic belting as mentioned in the Progress in Review columns.

We feel sure there are others who would welcome this information. Jules Borel and Co., 410 Altman Building, 103 E. 11th St., Kansas City 6, Mo., are the American manufacturers of this product.

Many Thanks

To the Editor:

May I compliment you on your editorial, "Some Are Merely Bricklayers," as published in the December issue of PRODUCT ENGINEERING. I have been so forcibly impressed that I would like a reprint.

I feel that local engineering clubs might do well to post a copy of this editorial in their meeting rooms.

—W. C. RODGERS, *Works Manager*
The Perkins-Elmer Corp.

Ed.—The reprint went out by return mail. We have a few more copies to give away.

A Matter of Concern

To the Editor:

In your February 1948 issue there is a notice on page 159 of my election as president of the Society of Automotive Engineers. It is there stated that I am chief engineer of Shell Development Co.; this is quite a serious error. Shell is a very good company, but I don't work for them. My company is Gulf Research & Development. —R. J. S. PIGOTT
Chief Engineer
Gulf Research & Development Co.

Ed.—Unfortunately, the publicity release announcing Mr. Pigott's installation was in grievious error and our news editor didn't catch it. Our apologies to Mr. Pigott.